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**THE GREAT ABITIBI DYKE,
SOUTHEASTERN SUPERIOR PROVINCE, CANADA**

by

Richard Ernst, B.A. (Hons.), M.Sc.

A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfilment of
the requirements for the degree of
Doctor of Philosophy

Department of Earth Sciences
Carleton University
Ottawa, Ontario
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acceptance of the thesis, **The Great Abitibi
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**"All we are given is possibilities-
to make of ourselves one thing or another."**

-Ortega y Gasset

ABSTRACT

The Great Abitibi Dyke (GAD) is one of the longest mafic dykes in the world and can be traced for more than 700 km across the Abitibi Belt, southeastern Superior Province, Canadian Shield. This east-northeast trending dyke consists of at least 17 overlapping en-echelon segments and its average dip is vertical, except at the northeast and southwest ends where steep northerly dips predominate. The width of the dyke increases towards its mid-length and ranges from 0.08 to 0.25 km.

The dyke consists of two compositional units, considered to be different magmatic pulses. Unit 1 occurs throughout the dyke, while unit 2 is restricted to the dyke interior along half of the dyke length. Rocks of unit 1 consist of olivine gabbro to diorite with plagioclase of composition An₇₀₋₄₀ and Or₀₋₁₀, olivine of composition Fo₆₀₋₃₀, and augite of composition En₇₅₋₅₅. Rocks of unit 2 consist of olivine gabbro to monzodiorite and contain plagioclase of composition An₄₀₋₂₀ and Or₅₋₄₀, olivine of Fo₃₅₋₂₀, and augite of En₆₀₋₄₅. All rocks are weakly saturated to undersaturated in silica.

Rocks of both units can be derived by fractional crystallization from a parental magma similar in composition to the chilled margin samples of unit 1. Unit 2 rocks show systematic variation in composition along strike, becoming relatively poorer in plagioclase and richer in mafic minerals towards the southwest, a trend which may correlate with increasing depth of exposure.

The parental magma has trace element chemistry that corresponds

to a 'within-plate' setting and was probably derived from an incompatible-element enriched mantle.

Palcomagnetic data indicate perhaps less than a hundred years between the cooling of units 1 and 2. Minor post-intrusive flexure of the dyke and host-terrane is also identified.

The anisotropy of magnetic susceptibility (AMS) data is consistent with subhorizontal magma flow in unit 1 rocks and a synformal feldspar foliation pattern in unit 2 rocks.

The age of the dyke is approximately coeval with Keweenawan volcanism in the Lake Superior Basin, compressional activity in the Grenville Province and intrusion of carbonatites in the Kapuskasing Structural Zone.

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While I, alone, am responsible for the content of this thesis, I do owe an enormous debt of gratitude to the many people who have supported me throughout this project. I wish them all to know deeply the difference they have made to me.

I am delighted that Profs. Keith Bell, Giorgio Ranalli and Ralph Kretz of the Ottawa-Carleton Geoscience Centre (OCGC) accepted me as their Ph.D. student, and I hope that their investment in me has been rewarded. In doing my research and in summarizing it as a thesis, my supervisors could always be counted on to demand precision in research and a clear exposition of the results.

Dave Sloski and Jacques Bisson were my field assistants; both worked hard and were remarkably patient with my fussiness in the details of collecting samples. I note with sadness the passing of my friend, Jacques, in January 1988.

Peter Jones (Carleton U.) and Ron Hartree (Ottawa U.), both, also, of the OCGC were "instrumental" in teaching me to collect data on the electron microprobe and XRF, respectively. Dr. Peter Belanger (GSC) did most of the ferrous iron determinations while the remainder were done under the patient and forgiving tutelage of John Loop (Ottawa U. and OCGC). Jim Maley (GSC) wrote the program to produce the geochemical maps of Appendix 7. Prof. Gordon West of the U. of Toronto, provided some field support in the summer of 1982 and loaned me a proton magnetometer. John Broome introduced me to MAGRAV2.

Paleomagnetic and anisotropy of magnetic susceptibility (AMS) data

were collected at the GSC laboratory of Dr. Walter Fahrig. Mat Payne and Dr. Ken Buchan kindly did thermal demagnetization on 7 samples and Keith Bodger did some of the AMS measurements. Dr. Ken Buchan permitted the use of samples collected by him from two traverses, 7' and 10', for paleomagnetic and AMS analysis.

The group at the GSC laboratory, i.e. Dr. Walter Fahrig, Dr. Ken Buchan, Ken Christie, Gary Freda and coffee-time regulars Darryl Abbinett and Tim West provided a delightful working environment characterized by generous advice and assistance in data analysis and interpretation, and also by an enlivening and passionate exchange of ideas especially at coffee-break.

My understanding of Pearce ratio diagrams (Appendix 6) was developed through discussions with Profs. Tony Fowler (OCGC) and Tom Pearce (Queen's U.).

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In wish to acknowledge the work of Werner Erhard and Associates, a technology of breakthrough for people, which I have used to become more effective as a scientist.

My wife, Tish, has been with me throughout this thesis. I treasure her love and partnership.

I dedicate this thesis to my parents, Mary Lou and Richard.

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LIST OF ACRONYMS

AF	Alternating Field (demagnetization)
AFM	Alkali ($\text{Na}_2\text{O} + \text{K}_2\text{O}$)- FeO_T - MgO (diagram)
AMS	Anisotropy of Magnetic Susceptibility
APWP	Apparent Polar Wandering Path
CAB	Calc-Alkaline Basalt
CIPW	Cross-Iddings-Pirsson-Washington (classification system)
CFB	Continental Flood Basalt
CRM	Chemical Remanent Magnetization
GAD	Great Abitibi Dyke
GSC	Geological Survey of Canada
IAB	Island Arc Basalt
INAA	Instrumental Neutron Activation Analysis
IRM	Isothermal Remanent Magnetization
KSZ	Kapuskasing Structural Zone
LOI	Loss-On-Ignition
LKT	Low-Potassium Tholeiite
MORB	Mid-Ocean Ridge Basalt
NPR	Normalized Pearce Ratio
NRM	Natural Remanent Magnetization
OCGC	Ottawa-Carleton Geoscience Centre
OFB	Ocean Floor Basalt
PEF	Present Earth's Field (magnetization direction)
QFM	Quartz-Fayalite-Magnetite
REE	Rare Earth Elements
SHO	Shoshonite
TAS	Total Alkalis vs Silica (diagram)
TRM	Thermal Remanent Magnetization
WPB	Within-Plate Basalt
XRF	X-Ray Fluorescence

CHAPTER 1

INTRODUCTION

1.1 PURPOSE

Mafic dykes are currently a focus of much interest (see the review volume edited by Halls and Fahrig, 1987). Dykes are the primary mode of mafic magma transport through the crust, and therefore, study of their emplacement and differentiation histories is important for understanding mafic magma systems, i.e. lava flows, dykes, sills, plutons, etc. Dykes are also important in regional tectonic synthesis. Comparison of the distribution and ages of dykes between different tectonic regions can allow pre-rift paleo-continental reconstructions. Also, variation in dyke geometry, e.g. dip and thickness, can provide a sensitive measure of block tilting and the variation in depth-of-exposure across a host terrane.

Until recently, most work on dykes has been at a reconnaissance-scale, sufficient only to outline the general characteristics of swarms. However, in order to address specific topics such as magma flow trajectory, degree of multiple intrusion, differentiation processes and degree of contamination, etc., detailed multi-disciplinary studies are required.

As a contribution to this effort, this thesis focuses on a single dyke, the Great Abitibi Dyke of the Superior Province, Canada. A detailed multi-disciplinary approach involving petrology and geomagnetics was used to determine the 'anatomy' and emplacement history of this dyke.

1.2 INTRODUCTION

The Abitibi dyke swarm, located in the southern Superior Province of the Canadian Shield (Fig. 1.1), consists of at least 10 major dykes. These dykes have been subjected to reconnaissance-scale paleomagnetic, geochronological and chemical studies (Fahrig et al., 1965; Larochelle, 1966; Goodwin et al., 1971; Gates and Hurley, 1973; Card et al., 1981; Fahrig and West, 1986; Condie et al., 1987) which revealed the dykes to be olivine diabases of alkali olivine basalt composition (on a total alkalis vs silica diagram), and to have a characteristic paleomagnetic remanence direction and an age of intrusion of approximately 1150 Ma. However, none of the individual dykes of the swarm has previously been studied in detail.

The longest dyke of the swarm, and one of the longest in the world, is the Great Abitibi Dyke (GAD), which is more than 700 km long and up to 0.25 km wide. The GAD trends N70°E and has sub-vertical dip. Starting from the Kapuskasing Structural Zone (KSZ), it extends across the entire length of the Abitibi belt, ending near the Grenville Front. The GAD has been dated at 1140.6 ± 2 Ma (2s uncertainty) using the U-Pb method on baddeleyite (Krogh et al., 1987).

1.3 OVERVIEW

1.3.1 Introduction

This thesis presents a detailed petrological and geomagnetic study of the GAD in order to determine its mode of emplacement and tectonic history. Many aspects of the history of the dyke were considered including the composition of the parental magma, timing and trajectory

of magma emplacement, degree of contamination by host rocks, crystallization history and post-emplacement block tilting. The tectonic setting of the dyke and its relationship to the Kapuskasing Structural Zone (KSZ), the Keweenaw Rift System and the Grenville Orogen were also evaluated in order to place the dyke into a regional tectonic context.

1.3.2 Data Collection

The data collected and modelled in this thesis include petrological data consisting of field observations, modal mineral analyses, whole-rock chemistry and mineral chemistry, and geomagnetic data consisting of paleomagnetic measurements, magnetic susceptibility measurements (both bulk and anisotropic components), and total-field magnetic profiles (both aeromagnetic and ground-magnetic).

While field observations were made at all traverses the most detailed work was done at traverse 7 (Fig. 1.1). Ground magnetic profiles were collected across the dyke at traverses, 2, 3, 7, 9, 10, 11, 12, 14, 15, and 16 using a proton magnetometer. Forty four aeromagnetic profiles were extracted from published maps.

One hundred and eighty seven samples, 1 to 2 kg in mass, were used for petrological and geochemical analysis (Fig. 1.2). These samples were collected across the dyke at 16 traverses. Where possible, samples were collected from a complete cross-section including chilled margins. Satellite dykelets were sampled along five traverses (#'s 2, 5, 9, 13 and 14). At traverse 4, samples were

collected from dykelets (10 cm wide) which intrude the GAD and are oriented parallel to the plane of the dyke. At traverses 7 and 10, host rock samples were also collected in order to evaluate the degree of cross contamination between dyke and host rock. The analytical procedures used in determining modal, mineral and whole-rock compositions are given in Appendix 1.

One hundred and fifty samples were used for both paleomagnetic and anisotropy of magnetic susceptibility (AMS) studies. The samples were collected from 14 traverses and the distribution of samples is given in Fig. 1.3. Of these, 45 were collected by Dr. K. Buchan, Geological Survey of Canada; the remainder were collected by the author. Samples were collected from both the margin and interior of the dyke and from satellite dykelets. Adjacent host rock samples were also collected for a paleomagnetic baked contact test. Some of geomagnetic samples from the GAD were also used in the petrological analysis. The analytical procedures used in measuring the paleomagnetic and magnetic susceptibility properties of the samples are given in Appendix 8.

1.3.3 Outline of Approach

Petrological data (Chapters 2 through 7) were used to evaluate the source and emplacement history of the dyke. Topics include: evidence for two major compositional units, the observation and explanation of longitudinal variation, the relative contributions of partial melting, fractional crystallization and crustal contamination, and the characteristics of the mantle source area.

The geometry of the dyke and its emplacement history were assessed using geomagnetic data (Chapters 8 through 11). A detailed map of the dyke was produced mainly from aeromagnetic data and this map formed the basis for evaluating the regional variation in the trend, thickness, en-echelon segmentation, fault offsets, and dip of the dyke. The trajectory of magma flow was assessed through AMS study. The timing of emplacement of different parts of the dyke was determined paleomagnetically.

Some results from this thesis are already published. The geodynamic setting of the Abitibi swarm has been discussed by Ranalli and Ernst (1986) and a preliminary overview of the geochemistry and geophysics of the GAD is given in Ernst et al. (1987). The theory and application of Pearce ratios (Appendix 6) is presented in Ernst et al. (1988).

Fig. 1.1: Regional setting of the Abitibi dyke swarm (modified from Fahrig and West, 1986) and sampling localities of the Great Abitibi Dyke. KSZ is Kapuskasing Structural Zone. Dyke-dips based on field measurements of the orientation of the dyke-host rock contact and of joint sets within the dyke (See Section 2.2.5).

Fig. 1.2: Distribution of samples used for petrological studies within the GAD. Note exaggerated across-dyke scale. Samples bracketed by short parallel lines are narrow dykes (dykelets) which either cross-cut the main phase of the dyke or the host-rock. Sample traverses are labelled 1 - 16; see Fig. 1.1.

Fig. 1.3: Distribution of sample used for paleomagnetic and AMS studies. Note exaggerated across-dyke scale. Samples bracketed by short parallel lines are narrow dykes (dykelets) which either cross-cut the main phase of the dyke or the host-rock. Sample traverses are labelled 2 - 16; see Fig. 1.1. Small dots denote single samples while large dots denote sites that consist of more than one sample. The arrows along traverses 5 and 10' point towards host-rock sites located 295 and 440 m away from the dyke centre, respectively.

Table 1.1: Location of Sample Traverses

Traverse Number	Latitude (North)	Longitude (West)
1	47° 52.5'	82° 37.6'
2	47° 52.7'	82° 37.2'
3	47° 58.7'	82° 19.5'
4	48° 00.1'	82° 15.0'
5	48° 04.3'	82° 03.1'
6	48° 08.3'	81° 47.2'
7	48° 11.1'	81° 35.0'
7'	48° 15.8'	81° 20.0'
8	48° 22.5'	81° 03.8'
9	48° 31.8'	80° 38.4'
10	48° 33.0'	80° 35.6'
10'	48° 33.2'	80° 34.5'
11	48° 33.7'	80° 33.2'
12	48° 53.3'	79° 30.3'
13	48° 53.6'	79° 29.1'
14	48° 55.1'	79° 25.1'
15	49° 35.1'	77° 06.1'
16	49° 52.8'	75° 46.8'

CHAPTER 2

FIELD OBSERVATIONS AND PETROGRAPHY

2.1 INTRODUCTION

The Great Abitibi Dyke (GAD) has been studied in outcrop and in thin section at 16 traverses located along approximately 550 km of its 700 km length (Fig. 1.2). Although observations were made at all traverses, the most detailed were undertaken at a particularly well-exposed cross-section of the dyke at traverse 7 (Fig. 1.1), located along highway 144 between Gogama and Timmins, Ontario. The outcrop at traverse 7 is nearly continuous across three quarters of the width of the dyke, and both margins are exposed (Fig. 2.1).

The GAD consists of unmetamorphosed gabbro and monzodiorite. The grain size varies from aphanitic to very coarse-grained. Plagioclase, augite, olivine, titanomagnetite and ilmenite are the most abundant minerals in rocks of the GAD. Accessory minerals include alkali feldspar, apatite, baddeleyite, biotite, and zircon.

The GAD can be divided into two units (units 1 and 2) on the basis of field observations (Section 2.2), thin section petrography (Section 2.3), and particularly on the basis of whole-rock and mineral chemistry (Chapters 3 and 4).

Throughout this thesis, grain-size classes follow those of Williams et al. (1982, p. 54): fine is < 1 mm average diameter of grains, medium is 1 to 5 mm, coarse is 5 to 30 mm, and very coarse is > 30 mm. Textural terms follow those outlined in the Basaltic Volcanism Study Project (1981, pp. 366-369).

2.2 FIELD OBSERVATIONS

2.2.1 Introduction

Unit 1 rocks typically have a random fabric, while unit 2 rocks are characterized, at most traverses, by the presence of a weak feldspar foliation (e.g. Plate 2.1). Unit 2 rocks are also coarser-grained than most unit 1 rocks.

Unit 1 and 2 rocks have separate geographic distributions within the dyke such that unit 2 rocks are always restricted to the dyke-interior. For instance, at traverse 7, the contact between unit 1 and 2 rocks occurs at about 30 m in from the dyke margin (Fig. 2.1).

2.2.2 Unit 1

Units 1a and 1b

At traverse 7 (and perhaps at traverse 6) rocks of unit 1 can be sub-divided into an outer unit 1a and inner unit 1b (Fig. 2.1). These sub-units are distinguished both by abrupt grain size changes at their mutual contacts and by mafic pegmatites which are locally intruded along the contact planes (Plates 2.2A and B). Rocks of unit 1a typically contain <35% mafic minerals, while those of unit 1b average 40%. (Fig. 2.2). Unit 1b rocks increase in grain size from fine to coarse towards the dyke interior.

Unit 1a rocks are also cut by irregular fine-grained 'dykelets' (0.5 to 2 m wide) probably belonging to unit 1b. These 'dykelets' locally contain 'xenoliths' of unit 1a rocks.

2.2.3 Unit 2

The transition from unit 1 to unit 2 rocks at traverse 7 is

marked by a change from a subophitic to an intergranular texture and by the development of a foliation defined by tabular plagioclase grains.

The mafic mineral content of unit 2 rocks (at traverse 7) averages about 50% by volume (Fig. 2.2). Rocks of unit 2 also contain diffuse and discontinuous mafic-rich zones (Plate 2.2C) which are roughly sub-parallel to the feldspar foliation. Some mafic-poor zones are also present at traverse 7 (and traverse 14). The mafic-rich bands contain up to 80% mafic minerals; some mafic-poor (leucocratic) zones contain only 30 to 35% mafic minerals.

At traverse 7, the feldspar foliation defines a synform whose axis runs parallel to the dyke trend and plunges about 10° to the east (Figs. 2.3 and 2.4). Unit 2 rocks from traverses, 5, 6, 9, 10, and 11 also show a weak feldspar foliation, but there is insufficient outcrop to determine the variation in foliation across unit 2 at these traverses.

2.2.4 Chilled Margin of Main Dyke and Associated Dykelets

Narrow (< 2 m wide) dykelets associated with the GAD typically trend sub-parallel to the trend of the main dyke. Along traverses 2, 5, 7, 9, 13 and 14 these dykelets cut the host rock adjacent to the dyke, and are termed satellite dykelets. At traverse 4 similar dykelets intrude the main dyke and on the basis of cross-cutting relationships are thought to post-date the main dyke.

One satellite dykelet (about 10 m from the main dyke on the north side of traverse 7) is crosscut by ~1 cm wide granitic dykelets. While

cross-cutting relationships suggest these granitic dykelets are later than the GAD, the granitic dykelets appear to grade smoothly into the host rock granite outside of the dyke. This suggests that these are 'rheomorphic' dykelets composed of host rock melted by the GAD and injected into the satellite dykelets (Laitakari, 1969).

One interesting feature of both the chilled margins and dykelets is the presence of plagioclase phenocrysts which form up to 10% of the rock volume (Plate 2.1D). These tabular-shaped, plagioclase phenocrysts are up to 1 cm long and are generally aligned parallel to the dyke (or dykelet) contacts.

At about 1.5 m from the dyke-host rock contact on the north side (of traverse 7), the GAD is finely banded with feldspar-rich and mafic mineral-rich layers 1 mm to 1 cm thick. The feldspar-rich bands are parallel to the trend of the dyke and tend to be thinner than the layers rich in mafic minerals. This texture is consistent with a mechanism of oscillation nucleation (McBirney and Noyes, 1979).

These near margin, chilled margin and dykelet samples are grouped with unit 1 rocks on the basis of chemistry (Chapter 3).

2.2.5 Dyke Dip

Dyke dip has been determined through field observations at traverses 2, 3, 4, 7, 10 and 16. At traverse 2, a dip of 80-85°N is estimated from the orientation of the dyke contact (measured over a vertical distance of 1 m) and from the orientation of joints within the dyke. At traverse 3, joints suggest a dip of 70°N. At traverse 4, dykelets which cut the middle and western margin of the main dyke have trend parallel to the main dyke and have a dip of 75°N; the main dyke

is assumed to have a similar dip. At traverse 7 the orientation of (a) weakly developed jointing, (b) the outer contact with host rock and (c) internal contacts between units 1a and 1b, and units 1b and 2, are consistent with a dyke dip of 70° to 80° S. At traverse 10, a vertical dip is measured at the contact. At traverse 16, joints within the dyke have a northerly dip of $80-85^{\circ}$.

At traverse 7 the foliation of unit 2 rocks defines an asymmetric synform such that (a) the foliation zone of the south limb is broader than that on the north limb, and (b) the trough zone of the synform (labelled C in Fig. 2.3) is shifted slightly northwards from the center of the dyke. These asymmetries suggest that the dyke had a non-vertical dip during crystallization of unit 2 magma.

The axis of the synform defined by feldspar foliation also plunges eastwards along the dyke at about 10° . Providing that the axis was originally horizontal, then the present plunge of the foliation is consistent with post-intrusive block tilting of about 10° towards the east.

2.2.6 Intrusion Order

The pattern of units observed at traverse 7 was caused by the nesting of multiple intrusions (Fig. 2.5). Unit 1a was intruded by unit 1b which was in turn intruded by unit 2. The lack of any chilled samples or satellite dykelets of unit 2 composition suggests that unit 2 was emplaced while unit 1b rocks were still 'soft' and provided a easy pathway for magma injection. The synformal foliation pattern developed by the rocks of unit 2 indicates some downward movement of

unit 2 magma during emplacement and crystallization. The foliation pattern is not a consequence of metamorphic deformation.

2.3 PETROGRAPHY

2.3.1 Introduction

Petrographic observations from a suite of 60 thin sections indicate that the primary igneous mineralogy is preserved and that the rocks are only weakly altered. Some olivine is partially replaced by serpentine and iddingsite, and augite is often rimmed by amphibole. Plagioclase is partially altered to fine-grained epidote and sericite.

2.3.2 Modal Analysis

Modal compositions for 44 thin sections were determined by point counting (Appendix 2, Figs. 2.6, 2.7 and Table 2.1). Although the modal abundances are highly variable throughout the sample suite, units 1 and 2 have similar average olivine, augite, titanomagnetite, apatite and biotite contents. It is therefore difficult to separate units 1 and 2 on the basis of mineral modes. Differences are only observed in average alkali feldspar and plagioclase abundances (Table 2.1).

Feldspar abundance ranges from about 40 to 85%. Both plagioclase and anorthoclase (untwinned) are present. In addition, trace amounts of orthoclase are found in two samples (RE8418.18, RE8208.04). The relative proportions of plagioclase and alkali feldspar (anorthoclase and orthoclase) differ between units 1 and 2. Unit 1 typically contains less than 2% alkali feldspar and 50 to 70% plagioclase, while unit 2 contains 10 to 20% alkali feldspar and 30 to 50% plagioclase.

Olivine abundance averages 10% in both unit 1 and unit 2 rocks. However, it is most abundant (30%) in unit 1 rocks and is completely absent in some unit 2 rocks. Augite makes up 5 to 30% of rocks of the GAD. It is least abundant in some unit 1 rocks but reaches a similar level of maximum abundance (30%) in both unit 1 and 2 rocks. Apatite content varies between 0.2 and 7.0%. The lowest apatite abundances are found in unit 1 rocks while the highest are found in unit 2 rocks (Appendix 2, Table 2.1). Iron-titanium oxides are the main opaque oxides; sulphides are only present in trace amounts. Iron-titanium oxide contents (ilmenite and titanomagnetite) range from 4 to 14%, and generally, ilmenite is more abundant than titanomagnetite. Biotite forms 1 to 2% of the rocks, and is commonly associated with the iron-titanium oxides.

Based on observations from traverse 7, rocks of unit 1b contain greater abundances of augite and iron-titanium oxides and lower feldspar contents than do other rock units from the GAD.

2.3.3 Modal Classification

Rocks from the GAD are classified on the basis of modal mineralogy using the clinopyroxene-olivine-plagioclase and quartz-alkali feldspar-plagioclase-feldspathoid ternary plots of Streckeisen (1976) (Fig.2.7).

Unit 1 samples generally have a ratio of alkali feldspar to total feldspar of less than 10% and are classified using the Pl-Cpx-Ol diagram as olivine gabbros. Unit 2 rocks generally have a greater percentage of alkali feldspar and have a plagioclase composition of $<An_{50}$. Using the Q-A-P-F diagram (not shown) these rocks are

monzodiorites.

The absence of nepheline, orthopyroxene and quartz in virtually all of the samples (Appendix 2) suggests that the magma was transitional between the tholeiitic and alkaline magma series.

2.3.4 Textures

Distinct textural differences were observed in thin section between rocks of units 1 and 2. Plagioclase in unit 1 samples is commonly intergrown with olivine, and both are partially surrounded by anhedral augite. Olivine occurs both as isolated grains and as groups of grains. Alkali feldspar is interstitial.

In unit 2 samples, alkali feldspar surrounds embayed (partially resorbed) plagioclase and also occurs interstitially. Unit 2 olivines typically occur as sub-rounded grains that commonly enclose apatite and iron-titanium oxides. Augites of unit 2 are also typically sub-rounded. Plagioclase, olivine and augite define an intergranular texture in rocks of unit 2.

Ilmenite occurs as: (1) isolated, anhedral grains, (2) irregularly-shaped regions in the cores of anhedral titanomagnetite grains (composite grains; Morse, 1980) and, (3) exsolution lamellae in anhedral titanomagnetite crystals. Iron-titanium oxides are commonly surrounded by biotite. No textural differences are observed between iron-titanium oxides in units 1 and 2.

In both units, apatite occurs as acicular to prismatic euhedral crystals up to 0.5 mm in size and is most abundant in rocks of unit 2.

The order in which mineral phases began to crystallize can be

inferred from textural observations (Williams et al., 1982, pp. 56-59). In chilled margin samples (such as RE8401.46 and RE8404.14), plagioclase (grain size < 5 mm) occurs as phenocrysts, indicating that plagioclase is the liquidus phase. For other samples, the order in which minerals begin crystallization can be inferred from the order in which minerals characteristically enclose one another. In general, the 'enclosed' mineral must have crystallized earlier than the 'host' mineral, although under certain conditions the 'enclosed' and 'host' minerals are coeval (e.g. although apatite is often 'enclosed' by other minerals in basalts, phosphorous saturation studies indicate that it must have been crystallizing at the same time as these minerals: Green and Watson, 1982).

Based on observations summarized in Table 2.2 the following general observations can be made:

(a) In unit 1 rocks, plagioclase and olivine began crystallization first and were followed by apatite and the iron-titanium oxides. Augite and alkali feldspar were the last phases to have begun crystallizing.

(b) In unit 2 rocks, the apparent liquidus minerals are apatite and iron-titanium oxides. Augite and olivine then started to crystallize followed by plagioclase and finally by alkali feldspar and biotite.

Geochemical modelling in chapters 5 and 6 indicate that all rocks of the GAD have fractionated predominantly plagioclase and olivine. Thus it would be predicted that plagioclase and olivine were co-liquidus minerals throughout the crystallization history of the GAD-

magma. However, textural data (summarized above) indicate early but not simultaneous crystallization of olivine and plagioclase in unit 1 samples and that in unit 2 rocks, plagioclase and olivine appear on the liquidus after apatite and titanomagnetite. There are a couple of reasons that the textural criteria for unit 1 and particularly unit 2 samples lead to a result inconsistent with the geochemical modelling. Slight variation in magma composition can produce very different sequences of crystallization (e.g. Yoder and Tilley, 1962). Perhaps this variation occurred on a hand-sample scale. Also, the textural criteria are not infallible and differences in nucleation rate between different minerals can complicate the textural identification of the order of crystallization.

2.4 CONCLUSIONS

Field observations and petrography can be used to identify two texturally and compositionally distinct units within the GAD, designated units 1 and 2. Unit 1 can be further subdivided into at least 2 sub-units. Units 1a, 1b and 2 represent nested multiple magma pulses, in which the order of intrusion is unit 1a, unit 1b and finally unit 2. Unit 2 is characterized by a feldspar foliation that defines a synformal pattern with axial plane sub-parallel to the dyke plane. Field observations reveal that the dyke generally has a steep dip.

TRAVERSE 7

Fig. 2.1: Outcrop map (plan view) showing the subdivisions of the Great Abitibi Dyke (units 1a, 1b and 2) and the granitoid host rock (+) at traverse 7. Capital letters locate the field photographs presented in Plate 2.2.

Plate 2.1: Photographs of slab surfaces of rocks of the GAD. A is a photo of sample RE8204.11 (traverse 4); B is of RE8208.04 (traverse 15); C is of RE8207.15 (traverse 14); D is of RE8207.13 (traverse 14). Scale bar is 1 cm long. A, B are both from unit 1 and show the range in colour index (% of mafic minerals) possible for unit 1 rocks. C is from the northeast end of unit 2 and shows the feldspar foliation (better seen on an outcrop scale) which is characteristic of unit 2 rocks. C is typical of the most feldspar-rich of unit 2 rocks. Unit 2 rocks with a greater colour index are present towards the southwest end of the dyke. D is from a chilled margin sample which contains phenocrysts of plagioclase.

Plate 2.2: Photographs taken in the field at traverse 7. See Fig. 2.1 for photo locations. A is located at the contact between units 1a (left side) and unit 1b (right side). B shows a larger field of view of the same area and shows that a pegmatitic phase is locally present along the contact between units 1a and 1b. (Internal contacts in A and B have been inked for greater clarity.) Note that the contacts are diffuse and that unit 1b is fine-grained against medium-grained unit 1a. C shows rock of unit 2 in the dyke interior. The light mineral is feldspar (mostly plagioclase). The dark minerals include augite, olivine and Fe-Ti oxides. Two textural features are of special note in C. Firstly, feldspar grains have tabular shape and tend to have a common orientation, which define a foliation whose normal lies parallel to the short dimension of the photograph. Secondly, note that the rock is streaked with mafic-rich regions. The long axes of these mafic-rich regions are roughly aligned parallel to the feldspar foliation.

Fig. 2.2: Variation in the relative abundances of mafic minerals (olivine + iron oxides + augite) to felsic minerals (plagioclase + alkali feldspar) at traverse 7. Abundances were determined by visual comparison with volume percentage estimation diagrams and are considered accurate to $\pm 5\%$ (absolute). 2(\\), 2(-) & 2(/) subdivide unit 2 on the basis of the dip of the feldspar foliation and correspond to the S, C and N groups of Figs. 2.3 and 2.4.

TRAVERSE 7

Fig. 2.3: Feldspar foliation data from unit 2 at traverse 7. Outcrops of granitic host rock are distinguished by crosses. Unit 2 is subdivided on the basis of the dip of the feldspar foliation into three groups, north (N), central (C) and south (S). The foliation data from each group is plotted in Fig. 2.4 where the symbols, ∇ , $\bullet$, and $\blacktriangle$ identify the data from the N, C, and S groups, respectively. The two 'dashed' foliation symbols indicate less precise measurements. The $\ast$ identifies places where the feldspar grains have random orientation.

FELDSPAR FOLIATION (NORMAL-TO-PLANES PLOTTED)

Fig. 2.4: Equal area stereonet plot showing the feldspar foliation data (normals to planes). All data are plotted on the lower hemisphere of the stereonet. The foliation data are divided into three groups (▼, ●, ▲) which correspond to the three regions, N, C and S, defined in Fig. 2.3. The data define a great circle which is perpendicular to the dyke trend of 70° .

Fig. 2.5: Intrusive relationships at traverse 7 displayed by cross sections of the dyke after emplacement of unit 1a, 1b and 2, respectively. Unit 2 shows synformal foliation defined by feldspars. Units 1a and 1b appear to have a random fabric.

Fig. 2.6: Bar diagrams showing modal mineral proportions in representative samples from the GAD. The data are tabulated in Table A2.1.

(Continued on next page)

Fig. 2.6

(Continued on next page)

Fig. 2.6

Table 2.1: Average Modal Compositions of Units 1 and 2

	Unit 1			Unit 2		
	N	$\bar{x}$	s	N	$\bar{x}$	s
Olivine	30	10.3	5.9	14	7.0	4.0
Plagioclase	29	60.8	7.6	13	43.2	10.5
Alkali Feldspar	29	2.2	2.4	13	12.0	6.1
Total Feldspar	30	62.9	6.3	14	57.2	10.8
Augite	30	14.3	6.6	14	19.8	6.7
Fe-Ti Oxides	30	7.6	2.7	14	7.0	2.3
Apatite	30	2.4	1.6	14	3.5	1.1
Biotite	30	1.7	1.0	13	3.6	2.2

N is the number of samples analyzed. One thin section was point-counted per sample. (Data tabulated in Table A2.1.)

$\bar{x}$ is the average percentage modal abundance.

s is one standard deviation of modal data.

Table 2.2: Order in which minerals began crystallizing (based on textural observations).

UNIT 1							
SAMPLE	PLAG.	OLIVINE	FE-TI OXIDES	APATITE	AUGITE	OPX.	ALKALI FELDSPAR
8207.06	B	A	D	C	E		
8203.15	A	A	C	D	E		
8209.06	A	B	C	D	E		
8204.14	A	A	D	C	E		
8203.14	A	A	C	D	E		
8206.03	D	C	B	A	E		
UNIT 2							
SAMPLE	PLAG.	OLIVINE	FE-TI OXIDES	APATITE	AUGITE	OPX.	ALKALI FELDSPAR
8205.04	A	E*	D	C	A		
8401.22	E	C	A	A	C		F
8401.18	E	C	A	A	C		F
8207.15	D	C	B	A	E		
8201.04	?	E	B	A	C	D	F
8207.07	E	C	B	A	D		?

A TO F = EARLY TO LATE

* IDdingsite

Fig. 2.7: Classification of rocks of the GAD based on the relative abundances of modal plagioclase, clinopyroxene and olivine (Streckeisen, 1976). An <50 and An >50 refer to the average composition of plagioclase. The data are grouped both by unit (1 and 2) and by the ratio of alkali feldspar to total feldspar.

CHAPTER 3

WHOLE-ROCK CHEMICAL COMPOSITION

3.1 INTRODUCTION

Whole-rock chemistry of the Great Abitibi Dyke (GAD) can be used to (a) evaluate the degree of contamination between the dyke and host rock, (b) discriminate between rocks of units 1 and 2, and (c) identify the processes responsible for inter-sample compositional variation.

One hundred and eighty seven samples were analyzed for major and trace elements (Appendix 5; analytical details given in Appendix 1). Fourteen samples were from the granitic and the andesitic host rocks located at traverses 7 and 10, respectively. The remaining samples were taken from the dyke. Ten samples from near the dyke margin either contain abundant alteration minerals or show marked grain-size variations over short distances, suggesting the presence of volatiles during crystallization. Due to the possibility of contamination by host rock fluids, these samples were not used in petrogenetic interpretation. Of the remaining samples, 8 were taken from fresh chilled margins and 14 were from fresh dykelets that cut both the host rock and the main dyke.

3.2 HOST ROCK CONTAMINATION

3.2.1 Introduction

Studies of in-situ, host rock contamination of gabbroic dykes, reviewed by Mohr (1987), suggest that bulk contamination of mafic sheets is rare, but that selective contamination may be relatively common.

Gates (1971) compared compositions of dykes that cut syenites with those that cut mafic volcanics, and found that K, Rb, and Sr contents as well as the $^{87}\text{Sr}/^{86}\text{Sr}$ initial ratio were higher for those dykes (particularly at their margins) intruded into syenites. Fratta and Shaw (1974) and Dostal and Fratta (1977) studied a single dyke >80 km long which cuts both granitic and mafic volcanic host rocks. They observed that the concentrations of K, Rb, Li, Tl and perhaps Ba are higher in parts of the dyke bordered by granite than by mafic volcanics. Enrichment in these elements was found across the entire width of the dyke.

There are other studies which observe only negligible amounts of contamination. For instance, dykes of the Grenville swarm are uncontaminated except to a minor degree in the margins of dykes hosted by marble (Kretz et al., 1985). Study of a 400 km long mafic dyke in West Greenland led to the conclusion that no significant in-situ contamination had occurred (Kalsbeek and Taylor, 1986).

3.2.2 Chemistry of Near-Margin Samples vs Host Rock Type

In-situ contamination of the GAD was assessed using a statistical comparison of the chemistry of near-margin samples with host rock type (Tables 3.1 and 3.2). At traverses 5, 6, 7, 12 and 13 the dyke is hosted by potassic granites and at the remaining traverses the dyke is hosted by volcanic and metamorphic rocks, mafic to intermediate in composition.

For most elements in Table 3.2 no correlation was observed between dyke chemistry and host rock composition. However, both Rb and

Sr contents in satellite dykelets, and Rb contents in the visibly altered, near-margin samples are higher adjacent to felsic than mafic host rocks, suggesting in-situ contamination of Rb and perhaps Sr.

The ratio of Ba abundance to other incompatible elements is characteristically constant for rocks of the GAD. However, in some satellite dykelet samples from traverse 14, both the Ba content and the Ba/incompatible element ratio are abnormally low, suggesting that some Ba may have been lost to the host rocks.

3.2.3 Compositional Profiles Across the Dyke-Host Rock Contact

The extent of in-situ contamination of the dyke by the host rock and the host rock by the dyke was examined in greater detail using compositional profiles across the dyke-host rock contact at traverses 7 and 10. At the former, the dyke is bordered by granitic host rock, and at the latter, by mafic-intermediate volcanics.

Traverse 7

The only field evidence regarding the possibility of contamination, is that within 0.5 m of the contact, the host rock granite is 'bleached' white in contrast to its normally pink colour further away. The narrow width of this 'contact' metamorphic zone and the absence of a complimentary altered zone in the dyke margin suggests that any cross-contamination between dyke and host rock was minor.

The change in composition (Fig. 3.1) between dyke and host rock is very sharp at traverse 7. This is particularly clear in profiles of Si, Ti, Fe, Mg, Ca, K, Mn, Y, Ba, Rb and Ni. The only potential cross-

contamination between the dyke and the granitic host rock is evidenced by the samples located within 0.5 meters of the contact. The chemistry of these samples is consistent with slight migration of Si, K, and Rb from the host rock granite into the dyke, and with migration of Ca and perhaps, Al, Mg and Ni from the dyke into the host rock. The gradual increase in Ca content over a 10 metre wide zone inwards from the dyke margin, is probably due to in situ differentiation rather than host rock contamination.

Traverse 10

At traverse 10, cross-contamination (from host rock to dyke and vice versa) was also evaluated (Fig. 3.2). For distances greater than 5 m away from the dyke the host rock consists of a fine-grained, volcanic rock of basaltic andesite composition with well-developed cleavage. However, at closer distances (between the dotted lines in Fig. 3.2), contact metamorphism has converted the volcanic host rock into a massive, fine-grained rock containing epidote. The sample at the contact (located by the open circle symbol) is a hybrid sample containing both volcanic rock and interspersed patches (probably irregular 'micro' dykelets) from the GAD.

Barium, K, Na, Sr, Zr and perhaps Mg, Nb, P, Rb and Ti may have migrated across the dyke - host rock contact. However, such effects are minor and extend no further than about 0.5 m from the contact. The anomalously high Ni content near the dyke margin is difficult to explain.

3.2.4 Summary

The evidence suggests that in-situ contamination of the dyke by the host rock is minimal and is essentially restricted to the outer 0.5 m of the dyke. Adjacent to mafic/intermediate volcanic host rock, the dyke may have been slightly depleted in Ba, K, Na, Sr and Zr, while adjacent to the granitic host rock, the dyke is slightly enriched in Ca, K, Rb and Si. Host rocks adjacent to the dyke have undergone some minor contact metamorphism; pink granitoid host rocks are 'bleached' white and mafic-intermediate volcanics are epidotized. The apparent absence of in situ contamination (Section 3.2) along with petrographic evidence showing that the rock-forming minerals have suffered only weak alteration (Section 2.3) support the use of whole-rock chemistry for modelling the igneous history of the GAD. There is no clear evidence that any significant element mobility has occurred.

3.3 UNIT 1 AND UNIT 2

The chemistry of the GAD is summarized in the histograms in Fig. 3.3. The majority of samples from the GAD are basaltic and have distinctively high Al, P and Ti contents relative to average basalts (Cox et al., 1979, pp. 14-19 and pp. 402-406). Most of the histograms (Fig. 3.3) are skewed and some are bimodal.

The bimodal distributions suggest two sample populations which correspond to units 1 and 2, discussed in Chapter 2. Barium is particularly useful as a chemical discriminant. Unit 1 rocks have less than 1300 ppm Ba, while unit 2 rocks have Ba contents greater than 1300 ppm. The average composition for each of the two units is listed in Table 3.3. In unit 2, elements such as Ba, K, Nb, Rb, Y and Zr are

enriched by a factor of about two, relative to unit 1 rocks. Chromium, Mg, Ni and V are more abundant in unit 1 than unit 2 rocks. Unit 1 and 2 are significantly different in chemistry for most of these elements, even those (such as Zr) for which the two standard deviation uncertainties partially overlap (Johnson, 1973, pp. 239-246).

Petrographic data from traverse 7 (Chapter 2) indicate that rocks of unit 1 and unit 2 can be separated spatially. The same conclusion can be made from the chemical data (Fig. 3.4A). Samples with a Ba content greater than 1300 ppm (unit 2) are restricted to the dyke interior over a length of 200 to 400 km. Rocks from this same region of the dyke also contain higher Zr contents (Fig. 3.5), lower Mg^* [$100 \cdot Mg / (Mg + Fe)$] (Fig. 3.4B) and higher values of the Differentiation Index (DI) (Fig. 3.4D) than unit 1 samples. Both Mg^* and DI measure the degree of differentiation of a magma, and it can be inferred from the data, that unit 2 rocks are more highly differentiated than unit 1 rocks.

3.4 CHEMICAL NOMENCLATURE

3.4.1 Introduction

In this section the data from the GAD are classified by magma type. Some samples from the GAD are thought to be cumulates (Chapter 5). On all of the classification diagrams given below, the data from cumulates plot separately from the rest of the data and are not used for assessing magma type.

3.4.2 Magma Type

A number of criteria can be used to classify magmas into one of

three broad types: tholeiitic, calc-alkaline or alkaline. Alkaline rocks are distinguished from subalkaline (tholeiitic and calc-alkaline) using CIPW normative mineralogy, the Nb/Y ratio, and the alkali-silica ratio (Yoder and Tilley, 1962; Winchester and Floyd, 1977; Irvine and Baragar, 1971), while the AFM diagram is used to separate tholeiitic from calc-alkaline types.

CIPW normative mineralogy is used to distinguish the degree of silica saturation. Silica saturated and over-saturated rocks (subalkaline) contain normative hypersthene, while silica under-saturated rocks (alkaline) contain normative nepheline or perhaps a few percent normative hypersthene. Some analyses from the GAD cluster along the diopside-olivine join, but most rocks are weakly hypersthene normative (Table A5.1) and would be classified as olivine tholeiites (Fig. 3.6). The CIPW normative classification is, however, strongly influenced by the iron oxidation state used in the norm calculation. Table 3.4 shows the shift in abundance in normative hypersthene and nepheline as a result of varying the iron oxidation state. The data in Fig. 3.6 were calculated using the measured $\text{Fe}_2\text{O}_3/\text{FeO}$ ratio which averages at -0.3 (Fig. 3.7). It is not known whether the measured $\text{Fe}_2\text{O}_3/\text{FeO}$ ratios were present during crystallization of the magma or are an effect of secondary oxidation. If the latter were true, then the original magmatic oxidation ratio might be more closely approximated by using the iron-splitting (into Fe^{2+} and Fe^{3+}) algorithm of either Brooks (1976) or Thompson et al. (1983). Using either of these algorithms, the normative data would cluster along the olivine diopside join (Fig. 3.6) and the magma series would be

identified as being transitional between olivine tholeiite and alkali basalt.

The ratio of Nb/Y can also be used to distinguish alkaline and subalkaline types (Winchester and Floyd, 1977). Using this ratio, most of the data straddle the saturated/under-saturated boundary (Fig. 3.8), and thus, give a similar result to that indicated by the CIPW norms. However, because of the analytical uncertainty associated with this ratio (given by the error-cross), a slightly different Nb/Y ratio could shift the bulk of the data into either the alkaline or subalkaline fields.

On another discriminant diagram, using total alkalis vs silica (Fig. 3.9), the GAD data plot clearly in the alkaline field. This is a very different result than was obtained from the CIPW norms and the Nb/Y ratio. Miyashiro (1978) has described three sub-types of the alkaline magma series, all of which are alkaline-rich, but each has a different degree of silica saturation that ranges from silica over-saturated to under-saturated. Using Miyashiro's classification, the data from the GAD fall into the category of weakly silica saturated rocks of the alkaline series.

Additional information regarding magma series is available from modal mineral analyses. Because rocks of the GAD contain essentially no modal orthopyroxene or nepheline, the degree of silica saturation during crystallization must have remained transitional between under-saturated and saturated.

On an AFM diagram (Fig. 3.10), unit 1 data tend to cluster while unit 2 data are distributed along a linear trend extending from the

high iron to high alkali corners of the AFM diagram (Fig. 3.10). Overall, the data follow a trend of iron enrichment followed by alkali enrichment. The AFM diagram is typically used to discriminate between subalkaline magma types, tholeiitic and calc-alkaline. The GAD data plot in the tholeiitic field (Fig. 3.10). Given that the GAD may have transitional to alkaline characteristics, comparison can be made with the chemistry of alkaline basalts from various alkaline provinces (e.g. the islands of Hawaii, Tristan da Cunha, St. Helena, Gough, and Tahiti) (see Fig. 2 in Irvine and Baragar, 1971). The GAD rocks are typically more iron-rich than these alkaline suites.

3.4.3 Rock Nomenclature

Rocks of the GAD can be classified in several ways. Equivalent volcanic names can be assigned using the TAS diagrams (Fig. 3.9); on the TAS diagram most data fall in the basalt and trachybasalt fields while some fall in the trachyandesite and basanite fields (Zanettin, 1984). Using CIPW normative abundances, rocks of the GAD can be classified as olivine basalts and olivine tholeiites. On the basis of modal mineralogy (Section 2.3.3) most unit 1 rocks are olivine gabbros, and most unit 2 rocks are monzodiorites.

3.5 LOG(X) VS LOG(Y) DIAGRAMS

3.5.1 Introduction

The compositional variation in rocks of the GAD can be due to one or more of the following processes: contamination (assimilation), crystallization, or partial melting.

The possibility of assimilation can be evaluated as follows.

Samples from throughout the GAD exhibit 'spidergrams' showing a great variation in abundance but remarkably similar shape (Chapter 7). Therefore to attribute intersample variation in chemistry to assimilation or assimilation-fractional crystallization (DePalolo, 1981) would require a contaminant with a similar spidergram shape to that of the GAD. The typical GAD spidergram has some distinct positive and negative anomalies and is not easily matched to any known contaminant. Therefore, it is unlikely that the compositional variation within rocks of the GAD is due to assimilation or assimilation-fractional crystallization. Furthermore, in-situ contamination was ruled out in Section 3.2.

Crystallization in igneous rocks is thought to be more closely approximated by fractional, than by equilibrium crystallization (McBirney, 1984, p. 171). This conclusion is supported in the case of the GAD by the observed heterogeneity of mineral chemistry on a thin section scale (Chapter 4), an observation which is probably incompatible with the mechanism of equilibrium crystallization.

The possibility that the samples are related by variable degrees of partial melting is best modelled by the process of batch partial melting (Gill, 1981, p. 143).

Fractional crystallization is modelled by the standard expression (Neumann et al., 1954):

$$C_L/C_0 = F^{(D-1)} \quad (3.1)$$

where C_0 and C_L are the initial and final concentrations of a trace element in a liquid, D is the bulk mineral:melt distribution coefficient and F is the fraction of the original melt remaining. Use

of this equation assumes no diffusion between melt and already-formed crystals and a constant value of D .

Batch partial melting is governed by the equation:

$$C_L/C_0 = 1/(F + D - F \cdot D) \quad (3.2)$$

The slope produced by data on a $\log(Y)$ vs $\log(X)$ plot during operation of each process is given by equations 3.3 and 3.4 which are derived from equations 3.1 and 3.2. Use of this equation assumes complete equilibrium between melt and already-formed crystals and a constant value of D .

For fractional crystallization

$$\text{SLOPE} = \frac{\log(C_L(Y)) - \log(C_0(Y))}{\log(C_L(X)) - \log(C_0(X))} = \frac{D_Y - 1}{D_X - 1} \quad (3.3)$$

For batch partial melting

$$\text{SLOPE} = \frac{\log(C_L(Y)) - \log(C_0(Y))}{\log(C_L(X)) - \log(C_0(X))} = \frac{\log(F + D_Y - F \cdot D_Y)}{\log(F + D_X - F \cdot D_X)} \quad (3.4)$$

A plot of the logarithms of pairs of elements can be used to distinguish between the processes of batch partial melting and fractional crystallization and also to calculate bulk distribution coefficients. For fractional crystallization, the data will follow a linear trend with a slope controlled by the values for D_X and D_Y . Such a slope will be independent of F . Analyses from cumulate and liquid portions of a fractionating magma will have identical slopes (Allegre et al., 1977) but different Y-axis intercepts (Cocherie, 1986). For the special case where both elements have equal distribution

coefficients $D_Y = D_X$, the slope equals 1, and the cumulate and liquid data trends are co-linear (Cocherie, 1986). This is most likely to occur if both elements are incompatible and $D_Y \approx D_X \ll 0$.

Batch partial melting produces parabolas (Gill, 1981, pp. 141-144), although for the special case of $D_Y = D_X = 0$, the slope equals 1.

The two processes are compared in Fig. 3.11. In this diagram it is assumed that the Y-axis variable is perfectly incompatible (i.e., $D_Y = 0$). The effects of varying D_X under each of the process is displayed in graphical form in Fig. 3.11. The larger the value of D_X (i.e., the greater the compatibility of X-axis variable), the more dissimilar are the partial melting and fractional crystallization curves. As D_X approaches 0, the fractional crystallization and partial melting curves become more similar and are indistinguishable when $D_X = 0$.

3.5.2 Results

The data from the GAD is shown on plots of $\log(Y)$ vs $\log(X)$ in Fig. 3.12. The logarithms of the abundances of the elements Ba, Zr, Y, K, Nb, Th, Ta, La, Ce, Sm, Eu, Yb, Hf and Rb are plotted against each other (Fig. 3.12A and 3.12B). Despite some scatter, on most plots the data define approximately linear trends, suggesting the rocks are cogenetic. In addition, the data trends have slopes approximately equal to 1, indicating that all of these elements have low distribution coefficients (approaching 0); i.e., they behave as incompatible elements. In the plots of Fig. 3.12C, the data are often scattered and slopes differ from a value of 1 because the X-axis

elements are behaving as compatible elements (see eqns. 3.3 and 3.4).

Barium was chosen for comparison with other elements because it shows a wide variation in abundance and is relatively well-determined. Barium was considered immobile because it co-varies in Fig. 3.12A and B with elements commonly considered to be more immobile such as Hf, Ta, Y, Zr and the REE (e.g. Humprhis, 1984 and references therein).

In most cases, unit 1 and unit 2 data fall along different parts of a common linear distribution. This lends further support to the division of the dyke into the two units. It also suggests that unit 1 and unit 2 rocks are cogenetic and that the same differentiation process is responsible for chemical variation between the two units and within each unit.

The plots in Fig. 3.12C are designed to display data representing an incompatible element on the Y-axis and various compatible elements on the X-axis. These data can be used to distinguish the effects of fractional crystallization and degree of partial melting. The slope of data on a plot of log (incompatible element) vs log (highly compatible element) can be compared with reference curves for fractional crystallization and partial melting (Fig. 3.11) over reasonable ranges of F . For fractional crystallization, F should range between 30% and 100% (see Fig. 4.6). For partial melting, F should range between 5% and 25%; the latter are reasonable estimates for producing basaltic magmas from mantle lherzolite. For these ranges of F , fractional crystallization and partial melting will cause distinctly different slopes in Fig. 3.11. The difference is greatest for an X-axis element with a large distribution coefficient, e.g., Ni and Co. The slope of

data on the $\log(\text{Ba})$ vs $\log(\text{Ni})$ diagram (Fig. 3.12C) is consistent with fractional crystallization for which the average value of D_{Ni} lies between 5 and 2 (Fig. 3.11A). This value of D_{Ni} is reasonable for the GAD (e.g. Cox et al., 1979, p. 334). Furthermore, the data-slope on the $\log(\text{Ba})$ vs $\log(\text{Ni})$ diagram (Fig. 3.12C) is not consistent with any reasonable batch partial melting curves (Fig. 3.11B). In a similar way, the $\log(\text{Ba})$ vs $\log(\text{Co})$ diagram in Fig. 3.12C can be interpreted to favour the process of fractional crystallization. It can therefore be concluded that the compositional variation in the GAD is most consistent with a process of fractional crystallization.

The elements which behaved compatibly (X-axis variables in Fig. 3.12C) can be linked to specific mineral phases removed from the parent magma during fractional crystallization. The degree of compatibility in Fig. 3.12C is reflected by the deviation of the data-slope from a value of 1. The greater the deviation the more compatible is the X-axis variable. The least compatible of the elements are Zn, Ti (for unit 1 samples only), Sc and P. The most compatible elements are Co, Ni, V and Sr. The abundance of Sr is controlled by plagioclase, that of Zn by iron-titanium oxides, sulphides and olivine, Ti and V by iron-titanium oxides, Co and Ni by olivine, Cr by clinopyroxene, Sc by clinopyroxene and plagioclase, and P by apatite (McBirney, 1984, p. 176; Carmichael, et al., 1974, pp. 13-22).

Bulk D values were calculated from the slopes (on plots of $\log(Y)$ vs $\log(X)$) where the Y-axis variable was considered to be perfectly incompatible (Table 3.5). Three different elements were selected as the Y-axis variable: Ba, Th and La. Each of these Y-axis

variables was paired with all other elements in turn as the X-axis variable. For each pairing of X- and Y-axis variables, the slope on a $\log(Y)$ vs $\log(X)$ graph was determined. Each slope-value was substituted into equation 3.3 (in which $D_Y = 0$) in order to calculate D_X . The results (Table 3.5) show that the calculated distribution coefficients, D_X , of each element are essentially the same regardless of whether Ba, Th or La is chosen as the perfectly incompatible element. Thorium is probably the most highly incompatible of the three elements and yields values of $D_X = 0.1$ for Ba and La. Thorium also appears to be more incompatible than Eu, Hf, Lu, Ta and Y. The slight differences in incompatibility among these elements cause the slight deviations from a slope of one which are exhibited by some plots in Figs. 3.12A and 3.12B.

The compatible elements (Y-axis variables in Fig. 3.12C) have D_Y values ranging up to 3.5 for Ni and Cr (calculated in Table 3.5 using combined unit 1 and unit 2 data).

3.5.3 Summary

In summary, the $\log(Y)$ and $\log(X)$ plots are useful in comparing unit 1 and 2 rocks, and in calculating the distribution coefficients of trace and minor elements using data from the GAD. Furthermore, it has been demonstrated that the compositional variation within the GAD is more consistent with fractional crystallization than with batch partial melting. The observed scatter in graphs of Fig. 3.12 may result from violation of the assumption that D was constant and that no diffusion occurred between melt and already-formed crystals.

3.6 CHILLED MARGIN SAMPLES

The compositions of chilled margins from along a considerable length of the dyke are listed in Table 3.6 and are all broadly similar in composition. Although the chilled margin samples contain some plagioclase phenocrysts, evidence presented in Section 7.2.2 shows that the plagioclase is not cumulus. Furthermore, wall-rock contamination is considered unlikely (see Section 3.2). Therefore, the compositions shown in Table 3.6 are probably representative of the composition of the original magma. In comparison with the other chilled margin compositions RE8401.46 generally has lower incompatible element contents, Zr, Ba, K and higher MgO, and Ni contents, and therefore, has the most primitive composition. The composition of RE8401.46 is used as the best estimate of the parental magma composition.

3.7 CONCLUSIONS

The GAD is only weakly metamorphosed, altered, and is essentially uncontaminated by its host rock. It has been demonstrated that unit 1 and unit 2 rocks differ in chemistry and that rocks of unit 2 appear to be more evolved than rocks of unit 1 (e.g. higher incompatible element and lower Ni and Mg contents). The chemical variation in the GAD is consistent with the changes brought about by fractional crystallization.

Table 3.1: Host rock type at each traverse

TRAVERSE NO.	TRAVERSE LABEL	HOSTROCK TYPE	HOSTROCK CODE	DATA SOURCE
1	8427	MAFIC TO INTERMEDIATE METAVOLCANIC	M	PM, F
2	8428	MAFIC TO INTERMEDIATE METAVOLCANIC	M	PM, F
3	8425	MAFIC TO INTERMEDIATE METAVOLCANIC	M	PM, F
4	8424 & 8204	MAFIC TO INTERMEDIATE METAVOLCANIC	M	PM, F
5	8203	BIOTITE GRANODIORITE, BIOTITE QTZ MONZONITE	F	PM, F
6	8430	GRANITE	F	F
7	8401	GRANITE	F	F
8	8205	MAFIC TO INTERMEDIATE VOLCANIC	M	PM, F
9	8403	MAFIC TO INTERMEDIATE VOLCANIC	M	PM, F
10	8404 & 8202	ANDESITIC VOLCANIC (SiO ₂ = 53%)	M	PM, F, C
11	8201	MAFIC TO INTERMEDIATE VOLCANIC	M	PM, F
12	8206	GRANITE	F	PM, F
13	8420	GRANITE	F	PM, F
14	8418 & 8207	HORNBLENDE SCHIST	M	PM, F
15	8208	QTZ DIORITE, GNEISS	M?	PM, F
16	8209	GREYWACKE, MAFIC LAVA, CONGLOMERATE	M?	P

HOSTROCK CODE:

F = GRANITIC, M = MAFIC TO INTERMEDIATE IN COMPOSITION

DATA SOURCE:

PM = PUBLISHED MAP, P = PRELIMINARY MAP, F = FIELD OBSERVATION

C = CHEMICAL ANALYSIS OF HOST ROCK

Table 3.2: Test for in situ contamination. The average composition of the dyke bordered by felsic host rock is compared with the average composition where bordered by mafic host rock. Host rock types are listed in Table 3.1.

(A) Samples from within 10 metres of contact + satellite dykelets

	Mafic Host Rock		Felsic Host Rock		Difference	P-Value
SiO ₂ (1s)	45.92	(0.67)	46.13	(0.88)	-0.21	0.352
TiO ₂	3.40	(0.46)	3.10	(0.63)	0.30	0.066
Al ₂ O ₃	17.36	(1.06)	18.01	(1.38)	-0.65	0.072
Fe ₂ O ₃ T	14.18	(0.96)	13.58	(1.57)	0.60	0.100
FeO	9.97	(0.73)	9.79	(1.34)	0.18	0.523
CaO	9.08	(0.38)	9.09	(0.61)	-0.01	0.940
MgO	6.11	(0.92)	6.22	(1.51)	-0.11	0.755
Na ₂ O	3.23	(0.26)	3.27	(0.26)	-0.04	0.645
K ₂ O	0.90	(0.26)	0.89	(0.22)	0.01	0.888
MnO	0.18	(0.02)	0.17	(0.02)	0.01	0.058
P ₂ O ₅	0.76	(0.17)	0.64	(0.19)	0.12	0.026
Zr	103	(16)	94	(20)	9	0.085
Y	23	(3)	22	(4)	1	0.091
Nb	15	(4)	13	(3)	2	0.113
Ba	791	(152)	747	(140)	44	0.332
Rb	12	(9)	11	(13)	1	0.857
Sr	857	(108)	926	(86)	-69	0.030
V	257	(57)	231	(45)	26	0.183
Ni	47	(18)	49	(23)	-2	0.704
Number of samples used:						
V	32		11			
Other elements	35		16			

(B) Samples from between 10 and 1.5 metres of contact

	Mafic Host Rock		Felsic Host Rock		Difference	P-Value
SiO ₂	45.80	(0.94)	46.22	(0.98)	-0.42	0.285
TiO ₂	3.42	(0.43)	2.96	(0.72)	0.46	0.055
Al ₂ O ₃	17.81	(0.93)	18.46	(1.46)	-0.65	0.182
Fe ₂ O ₃ T	13.93	(0.93)	13.21	(1.76)	0.72	0.188
FeO	9.96	(0.74)	9.84	(1.56)	0.12	0.798
CaO	9.14	(0.35)	9.22	(0.62)	-0.08	0.690
MgO	5.98	(1.11)	6.21	(1.83)	-0.23	0.695
Na ₂ O	3.28	(0.27)	3.25	(0.28)	0.03	0.803
K ₂ O	0.87	(0.19)	0.82	(0.17)	0.05	0.545
MnO	0.17	(0.01)	0.17	(0.02)	0.00	0.470
P ₂ O ₅	0.71	(0.18)	0.58	(0.20)	0.13	0.094
Zr	100	(21)	89	(20)	11	0.229
Y	22	(4)	20	(4)	2	0.167
Nb	14	(4)	12	(3)	2	0.343
Ba	802	(140)	724	(130)	78	0.164
Rb	8	(6)	7	(3)	1	0.571
Sr	920	(62)	957	(87)	-37	0.215
V	269	(66)	224	(55)	45	0.142
Ni	43	(18)	48	(27)	-5	0.619
Number of samples used:						
V	13		7			
Other elements	15		11			

(Continued on next page)

Table 3.2

(C) Samples from within 1.5 metres of contact

	Mafic		Felsic		Difference	P-Value
	Host	Rock	Host	Rock		
SiO ₂	46.14	(0.44)	45.81	(1.20)	0.33	0.501
TiO ₂	3.08	(0.63)	3.36	(0.19)	-0.28	0.557
Al ₂ O ₃	17.61	(1.34)	17.22	(0.32)	0.39	0.704
Fe ₂ O ₃ T	13.82	(1.32)	14.36	(1.15)	-0.54	0.610
FeO	9.79	(0.84)	9.01	(0.74)	0.79	0.269
CaO	9.06	(0.29)	9.10	(0.12)	-0.04	0.856
MgO	6.44	(1.03)	6.21	(0.74)	0.23	0.784
Na ₂ O	3.24	(0.21)	3.23	(0.41)	0.01	0.946
K ₂ O	0.83	(0.14)	0.87	(0.31)	-0.04	0.807
MnO	0.18	(0.02)	0.18	(0.01)	0.00	0.978
P ₂ O ₅	0.70	(0.19)	0.66	(0.04)	0.04	0.815
Zr	101	(13)	96	(21)	5	0.649
Y	22	(2)	24	(1)	-2	0.336
Nb	13	(4)	15	(3)	-2	0.615
Ba	803	(90)	764	(198)	39	0.668
Rb	8	(2)	9	(3)	-1	0.587
Sr	893	(81)	882	(6)	11	0.866
V	221	(56)	226	(-)	-5	0.941
Ni	58	(25)	51	(13)	7	0.743
Number of samples used:						
V		8		1		
Other elements		8		2		

(D) Samples from within 1.5 metres of contact including samples RES204.15, RES204.08, RES401.47, RES404.15, RES202.08, RES202.05, RES202.02, RES418.13A and RES207.09 all of which show textural evidence for the presence of volatiles during crystallization (Section 3.1).

	Mafic		Felsic		Difference	P-Value
	Host	Rock	Host	Rock		
SiO ₂	46.93	(2.59)	47.77	(3.50)	-0.84	0.627
TiO ₂	3.25	(1.11)	3.55	(0.35)	-0.30	0.653
Al ₂ O ₃	16.92	(1.64)	15.99	(2.14)	0.93	0.398
Fe ₂ O ₃ T	13.83	(1.24)	14.16	(0.89)	-0.33	0.671
FeO	9.60	(1.32)	8.33	(1.29)	1.27	0.143
CaO	9.07	(1.32)	8.58	(0.91)	0.49	0.555
MgO	6.37	(1.10)	5.46	(1.40)	0.91	0.223
Na ₂ O	3.19	(0.36)	3.22	(0.29)	-0.03	0.864
K ₂ O	0.76	(0.20)	1.11	(0.48)	-0.35	0.038
MnO	0.18	(0.02)	0.17	(0.02)	0.01	0.471
P ₂ O ₅	0.58	(0.23)	0.91	(0.43)	-0.33	0.059
Zr	94	(17)	97	(15)	-3	0.813
Y	21	(4)	23	(2)	-2	0.290
Nb	12	(4)	11	(7)	1	0.722
Ba	707	(141)	737	(148)	-30	0.747
Rb	8	(4)	17	(15)	-9	0.027
Sr	786	(177)	833	(84)	-47	0.662
V	275	(160)	287	(86)	-12	0.925
Ni	52	(20)	36	(27)	16	0.243
Number of samples used:						
V		15		2		
Other elements		16		3		

(Continued on next page)

Table 3.2

(E) Samples from within 1.5 metres from the contact + satellite dykelets

	Mafic		Felsic		Difference	P-Value
	Host	Rock	Host	Rock		
SiO ₂	46.01	(0.36)	45.92	(0.76)	0.09	0.710
TiO ₂	3.38	(0.49)	3.41	(0.14)	-0.03	0.915
Al ₂ O ₃	17.02	(1.04)	17.02	(0.32)	0.00	0.991
Fe ₂ O ₃ T	14.36	(0.96)	14.41	(0.70)	-0.05	0.932
FeO	9.98	(0.75)	9.42	(0.67)	0.56	0.177
CaO	9.03	(0.40)	8.74	(0.56)	0.29	0.240
MgO	6.22	(0.77)	6.30	(0.44)	-0.08	0.831
Na ₂ O	3.19	(0.25)	3.31	(0.28)	-0.12	0.411
K ₂ O	0.92	(0.31)	1.01	(0.30)	-0.09	0.597
MnO	0.19	(0.02)	0.18	(0.01)	0.01	0.315
P ₂ O ₅	0.79	(0.15)	0.74	(0.10)	0.05	0.514
Zr	106	(11)	103	(16)	3	0.620
Y	24	(3)	24	(2)	0	0.951
Nb	16	(4)	14	(2)	2	0.435
Ba	783	(163)	771	(173)	12	0.890
Rb	14	(10)	21	(25)	-7	0.330
Sr	810	(113)	855	(33)	-45	0.453
V	249	(50)	241	(27)	8	0.812
Ni	50	(18)	55	(9)	-5	0.621
Number of samples used:						
V		19		3		
Other elements		20		4		

(F) Satellite dykelets

	Mafic		Felsic		Difference	P-Value
	Host	Rock	Host	Rock		
SiO ₂	45.92	(0.27)	46.02	(0.22)	-0.10	0.660
TiO ₂	3.59	(0.23)	3.46	(0.09)	0.13	0.466
Al ₂ O ₃	16.63	(0.55)	16.83	(0.23)	-0.20	0.615
Fe ₂ O ₃ T	14.73	(0.36)	14.45	(0.37)	0.28	0.346
FeO	10.11	(0.69)	9.82	(0.35)	0.29	0.587
CaO	9.00	(0.47)	8.38	(0.64)	0.62	0.123
MgO	6.07	(0.52)	6.39	(0.01)	-0.32	0.413
Na ₂ O	3.16	(0.28)	3.40	(0.18)	-0.24	0.288
K ₂ O	0.98	(0.38)	1.15	(0.29)	-0.17	0.548
MnO	0.20	(0.01)	0.18	(0.00)	0.02	0.133
P ₂ O ₅	0.86	(0.06)	0.82	(0.08)	0.04	0.463
Zr	109	(8)	110	(11)	-1	0.928
Y	26	(3)	25	(2)	1	0.507
Nb	18	(3)	14	(1)	4	0.069
Ba	770	(201)	777	(225)	-7	0.966
Rb	18	(12)	34	(35)	-16	0.206
Sr	755	(98)	827	(14)	-72	0.339
V	268	(36)	249	(34)	19	0.497
Ni	45	(9)	58	(7)	-13	0.068
Number of samples used:						
V		11		2		
Other elements		12		2		

(Continued on next page)

Table 3.2

Notes on Table 3.2

Major element data were first normalized to 100%

1s = one standard deviation

P-Value is the probability level at which the means are different. A P-Value of 0.050 indicates that the means are significantly different at the 95% confidence level. The t test was done using pooled variances (Johnson, 1973, p. 268)

Number of samples from each traverse used for comparison in A through F above. Number in parentheses is for V.

Adjacent to mafic host rock

	Traverse#	1	2	3	4	8	9	10	11	14
A		2	6(3)	1	3	3	2	4	1	13
B		2	2(0)	1		2		2	1	4
C			2					2		4
D			2		1	1		6		6(5)
E			4(3)		3		2	2		9
F			2(1)		3		2			5

Adjacent to felsic host rock

	Traverse#	5	6	7	12	13
A		2	3	5(0)	1	5
B		1	3	4(0)	1	2
C				1(0)		1
D				2(1)		1
E		1		1(0)		2
F		1				1

Analyses from traverses 15 and 16 not used because host rock type is uncertain.

Fig. 3.1: Evaluation of in-situ contamination at traverse 7. Chemical data are plotted along a profile perpendicular to the dyke trend, centered on the dyke-host rock contact. ● = dyke samples and ▲ = granitic host rock samples. The dashed line marks the contact. For the major elements the analytical uncertainty (2s) is no larger than the size of the symbols used for plotting (Table A1.6). For minor and trace elements the error ranges up to approximately twice the size of the plot symbol.

Fig. 3.2: Evaluation of in-situ contamination at traverse 10. Chemical data are given along a profile perpendicular to the strike of the dyke, centered on the dyke-host rock contact. The host rock is andesitic. ● = dyke samples, while ▲ = andesitic host rock samples. The ○ locates a hybrid sample on the contact. The dotted line at the 0 metre position marks the contact. A zone of contact metamorphosed host rock is located between the two dotted lines. Analytical uncertainties are the same as in Fig. 3.1.

TRAVERSE 10

Fig. 3.3: Histograms showing chemical compositions from the Great Abitibi Dyke. Filled regions have Ba contents less than 1300 ppm. Open regions have Ba contents greater than 1300 ppm. All oxide values are given in weight percent, trace elements in ppm. La/Yb values are not chondrite normalized. Eu/Eu^* gives the magnitude of the Eu anomaly (Eu^* is europium content interpolated from adjacent trivalent rare earth elements). $An^* = 100 \cdot An / (An + Ab + Ne \cdot 5/3)$ where An, Ab and Ne are CIPW normative minerals divided by their molecular weight. $Mg^* = \text{molar } 100 \cdot Mg / (Mg + Fe^{2+})$. DI (Differentiation Index) = $Q + Or + Ab + Ne + Ks + Lc$ (CIPW normative mineral abundances). Figure from Ernst et al. (1987).

Table 3.3: Chemical composition of the GAD

UNIT 1				UNIT 2		
	No. of Analyses	Mean	1S	No. of Analyses	Mean	1S
SiO ₂	121	46.47	1.35	42	48.64	2.95
TiO ₂	121	3.39	0.79	42	3.19	0.74
Al ₂ O ₃	121	17.71	1.60	42	14.64	2.67
Fe ₂ O ₃	121	2.86	0.69	42	3.63	0.86
FeO	121	9.70	1.26	42	10.87	3.20
MgO	121	5.32	1.36	42	2.97	0.86
CaO	121	9.15	0.61	42	8.23	0.63
Na ₂ O	121	3.42	0.33	42	4.09	0.58
K ₂ O	121	1.00	0.26	42	1.91	0.23
P ₂ O ₅	121	0.81	0.38	42	1.61	0.44
MnO	121	0.17	0.02	42	0.22	0.06
Zr	121	108.	22.	42	188.	30.
Y	121	24.	5.	41	41.	4.
Nb	121	15.	4.	42	27.	4.
Zn	121	103.	24.	42	142.	27.
Ba	121	835.	165.	42	1554.	142.
Rb	121	13.	9.	42	26.	6.
Sr	121	890.	110.	42	718.	99.
Ni	121	34.	23.	42	<5	-
Cr	7.	61.	30.	19	15.	18.
V	95	243.	71.	20	136.	52.
Co	45	41.	8.	6	32.	12.
Ta	45	1.4	0.3	6	2.3	0.3
Sc	45	21.	4.	6	29.	9.
Hf	45	2.4	0.5	6	3.9	1.1
Th	43	1.3	0.4	6	2.5	0.5
La	45	24.	6.	6	43.	4.
La/Yb	45	12.5	0.8	6	12.1	0.8
Eu/Eu*	45	1.5	0.2	6	1.3	0.2
An#	121	66.	4.	42	46.	6.
Mg#	121	49.	5.	42	33.	4.
D.I.	121	35.	4.	42	46.	6.

Major element analyses were normalized to 100% before being averaged. All oxide values are given in weight percent. All trace elements are in ppm. La/Yb, Eu/Eu*, An#, Mg# and D.I. are described in caption of Fig. 3.3.

Fig. 3.4: Chemical maps of the GAD. Closely spaced horizontal lines represent host rock. Data from unit 2 rocks are enclosed by a thick line. Ba is in ppm, FeO and Al₂O₃ are in wt% and Mg# and DI are defined in Fig. 3.3. Figure from Ernst et al. (1987)

Table 3.4: Effect of the oxidation state of Fe on the CIPW norm

Sample No.	A		B		C		D	
	This thesis		Thompson et al. 1983		Brooks, 1976		Irvine and Baragar, 1971	
	$\text{Fe}_2\text{O}_3/\text{FeO} \approx 0.3$		$\text{Fe}_2\text{O}_3 = 1.5$		$\text{Fe}_2\text{O}_3/\text{FeO} = .15$		$\text{Fe}_2\text{O}_3 = \text{TiO}_2 + 1.5$	
	hy	ne	hy	ne	hy	ne	hy	ne
RE8428.02	4.3	0	1.2	0	0.8	0	6.1	0
RE8428.07	0.6	0	0	2.3	0	0.3	7.7	0
RE8425.07	7.9	0	4.6	0	4.8	0	9.8	0
RE8203.12	7.4	0	0.6	0	2.7	0	9.3	0
RE8401.04	0	1.1	0	1.3	0	1.3	1.9	0

hy is CIPW normative hypersthene

ne is CIPW normative nepheline

All calculations done on the basis of wt%.

Group A: FeO was measured by titration and Fe_2O_3 was calculated as the difference from $\text{Fe}_2\text{O}_3\text{T}$

Fig. 3.5: Cross-section profiles for Ba and Zr. Traverses 2, 3, 4, 5, 7, 10, 14, 15 and 16 are given in order from WSW to ENE along the GAD. Ba and Zr contents are given in ppm. The 2s analytical uncertainties, 30 ppm for Ba and 14 ppm for Zr (Table A1.6), are small relative to the range of compositional variation in the profiles of this figure. The thick bar locates unit 2 (dashed where uncertain). The line underneath the bar indicates the full dyke-width. Figure from Ernst et al. (1987).

Fig. 3.6: CIPW normative abundances. Average measured ratio, $\text{Fe}_2\text{O}_3(\text{wt}\%)/\text{FeO}(\text{wt}\%) = 0.3 \pm 0.1$ (Is) (See Fig. 3.7). Legend: + = data from unit 2 samples ($\text{Ba} > 1300$ ppm). The remaining symbols represent data from unit 1 samples; these are divided into four groups. ◊ = satellite dykelets close to the main dyke. △ = dyke-margin samples. ▽ = samples with $\text{Ba} < 800$ ppm (probably cumulates). ◻ = remaining unit 1 samples.

Fig. 3.7: Plot of Fe₂O₃T vs FeO (in wt%). Fe₂O₃T is total iron expressed as ferric oxide. Average Fe₂O₃/FeO has an average value of 0.3 ± 0.1 (1s). Letters correspond to ranges in Al₂O₃ content. The 2s analytical uncertainties are no larger than the size of the letters used for plotting (Table A1.6).

Fig. 3.8: SiO_2 vs Nb/Y diagram used for classification. $\text{Nb/Y} = 0.67$ divides between alkaline and subalkaline rock types. Diagram after Winchester and Floyd (1977). Symbols same as in Fig. 3.6. The cross indicates the average $\pm 2s$ analytical uncertainty (Table A1.6)

Fig. 3.9: TAS diagram (Total Alkalies vs Silica). Alkaline-subalkaline dividing line after Irvine and Baragar (1971); additional fields after Zanettin (1984). Symbols same as in Fig. 3.6. The cross indicates the average $\pm 2\sigma$ analytical uncertainty (Table A1.6).

Fig. 3.10: AFM-diagram. Line separates rocks of calc-alkaline affinity from those of tholeiitic affinity. Dividing line is after Irvine and Baragar (1971). Data symbols same as in Fig. 3.6. FeO_T is total iron expressed as ferrous oxide. The 2 σ analytical uncertainty in each component is less than the size of the symbols.

Fig. 3.11: Theoretical curves illustrating the effects of fractional crystallization and batch partial melting on $\log(X)$ vs $\log(Y)$ diagrams. C_O and C_L are the initial and final concentrations of a trace element, and $F\%$ is the percentage amount of melt. D_X and D_Y are bulk distribution coefficients. In both diagrams $D_Y = 0$ (i.e., the Y-axis variable behaves incompatibly). D_X varies between 5, 2, 1, 0.5, 0.1 and 0. Each curve is labelled with its appropriate value of D_X . These diagrams are designed so that they can be compared with the diagrams in Fig. 3.12. The Y-axis ranges over 1 log unit which is approximately the same as the Y-axis range in Fig. 3.12. The X-axis ranges over 2 log units, which is twice the range on most diagrams in Fig. 3.12. Along the $D_X=5$ and $D_X=2$ lines in both A and B, the range of typical values of F for both processes are marked by the hatched areas. For fractional crystallization, $F = 30\%$ to 100% . For partial melting $F = 10\%$ to 20% . See discussion in text.

Fig. 3.12: Log(X) vs Log(Y) plots of pairs of elements. A line of slope equal to 1 is shown on each diagram. Legend: + = unit 2 (Ba > 1300 ppm). All other samples are from unit 1 and are divided into four groups. X indicates altered samples from near the dyke margin. $\diamond$ = samples from satellite dykes close to the main dyke. $\triangle$ = near margin fresh samples. $\square$ = all remaining unit 1 samples. Crosses indicate the $\pm 2s$ analytical uncertainty.

(A) rare earth elements plotted against each other and against Ba.
 (B) other incompatible elements on Y-axis; Ba and Zr on X-axis.
 (C) compatible and weakly incompatible elements on Y-axis; Ba on X-axis.

Fig. 3.12A

INCOMPATIBLE ELEMENTS

- SATELLITE DYKES (UNIT 1)
- △ MARGIN OF MAIN DYKE (UNIT 1)
- ◻ UNIT 1 FROM INTERIOR OF MAIN DYKE
- ◊ UNIT 2
- × VISIBLY ALTERED

(Continued on next page)

Fig. 3.12A

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2

MicroD

Fig. 3.12B

INCOMPATIBLE ELEMENTS

- SATELLITE DYKES (UNIT 1)
- △ MARGIN OF MAIN DYKE (UNIT 1)
- ◻ UNIT 1 FROM INTERIOR OF MAIN DYKE
- ◊ UNIT 2
- x VISIBLY ALTERED

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Fig. 3.12B

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Fig. 3.12B

(Continued on next page)

Fig. 3.12C

COMPATIBLE ELEMENTS

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Fig. 3.12C

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Fig. 3.12C

Table 3.5: Bulk distribution coefficients calculated from the data-slope on a $\log(A)$ vs $\log(B)$ plot (e.g. Fig. 3.12). This assumes a process of fractional crystallization. Calculations were done using the data from Table A5.1. $\text{SLOPE} = (D_A - 1)/(D_B - 1)$. D_B is calculated assuming D_A equals zero. A = Ba, Th, and La in turn.

B	$D_{Ba} = D_A$ $D_A = 0$		$D_{Th} = D_A$ $D_A = 0$		$D_{La} = D_A$ $D_A = 0$	
	D_B	$S(D_B)$	D_B	$S(D_B)$	D_B	$S(D_B)$
Zr	0.011	0.035	0.130	0.077	0.001	0.094
Y	0.073	0.035	0.184	0.068	0.064	0.044
Nb	-0.258	0.057	-0.107	0.108	-0.270	0.090
Ba	0.000	0.000	0.120	0.073	-0.010	0.072
Ta	0.183	0.055	0.281	0.054	0.175	0.040
Hf	0.084	0.082	0.194	0.066	0.075	0.072
Th	-0.137	0.094	0.000	0.000	-0.148	0.079
La	0.010	0.070	0.129	0.060	0.000	0.000
Ce	-0.010	0.076	0.111	0.064	-0.020	0.021
Nd	-0.128	0.092	0.007	0.079	-0.139	0.046
Sm	-0.065	0.087	0.063	0.080	-0.076	0.031
Yb	-0.006	0.069	0.115	0.066	-0.016	0.026
Lu	0.079	0.067	0.190	0.061	0.070	0.036
Ti	0.205	0.062	0.300	0.099	0.197	0.112
P	-0.576	0.085	-0.386	0.158	-0.591	0.113
K	-0.202	0.042	-0.058	0.068	-0.214	0.089
Zn	0.239	0.049	0.331	0.086	0.232	0.091
Rb	-1.102	0.126	-0.849	0.213	-1.123	0.259
Sr	1.490	0.032	1.431	0.051	1.495	0.053
V	2.328	0.113	2.168	0.128	2.341	0.166
Ni	3.420	0.186	3.129	0.266	3.443	0.322
Cr	3.469	0.200	3.172	0.289	3.493	0.309
Co	1.778	0.082	1.685	0.073	1.786	0.091
Sc	0.340	0.086	0.419	0.077	0.333	0.078
Eu	0.229	0.062	0.322	0.055	0.221	0.035

Best fitting slope are calculated using the 'reduced major axis' method discussed in York (1966). According to this method the slope equals:

$$\text{SLOPE} = S_Y/S_X (1 \pm [(1-R^2)/N]^{0.5})$$

where S_Y and S_X are the standard deviations of the $\log(A)$ and $\log(B)$ data, R is the correlation coefficient and N is the number of data points used. $N = N_Y$ if $N_Y < N_X$, or $N = N_X$ if $N_Y > N_X$. $S(D_B)$ is one standard deviation error in the calculated distribution coefficient.

$$S(D_B) = [(1-R^2)/N]^{0.5} * (1-D_B)$$

(See error propagation equations in Kretz, 1985).

Negative values for D_B are meaningless and must be due to: (1) $D_A > D_B$ in violation of an assumption of the method, (2) analytical uncertainty, or (3) in the case of Rb, contamination by host rock.

Table 3.6: Chilled margin compositions

Traverse #:	7	10	10	14	14	14	14	15	Weighted
Sample #:	REB401.46	REB404.14	REB404.13	REB207.04	REB207.03	REB207.05	REB207.01	REB208.09	Average ¹
SiO ₂	46.74	46.84	45.98	46.08	45.75	45.82	45.59	44.70	45.17
TiO ₂	3.48	2.91	3.53	3.16	3.42	3.44	3.48	3.46	3.38
Al ₂ O ₃	16.90	16.56	17.46	17.32	16.73	16.40	16.46	16.22	16.71
Fe ₂ O ₃ ^T	15.10	14.65	13.92	13.99	14.40	14.83	14.68	14.63	14.62
FeO	8.44		9.16					10.42	9.34
FeO(calc) ²	10.72	10.40	9.88	9.93	10.22	10.53	10.42	10.39	10.38
MgO	6.70	7.80	5.27	6.33	6.23	6.54	6.22	6.28	6.46
CaO	9.14	8.47	9.24	9.04	8.89	8.86	8.88	8.77	8.92
Na ₂ O	2.92	2.77	3.36	3.22	3.24	3.28	3.50	3.09	3.10
K ₂ O	0.64	0.61	0.84	0.90	0.93	0.92	0.95	0.99	0.82
P ₂ O ₅	0.63	0.66	0.90	0.68	0.81	0.77	0.84	0.83	0.75
MnO	0.18	0.18	0.18	0.18	0.18	0.19	0.19	0.20	0.19
LOI				0.44	0.14	0.27	0.15		0.25
Total ³	99.54	98.35	99.68	100.25	99.60	100.19	99.83	98.06	99.33
Zr	81	100	114	97	103	109	114	113	102
Y	23	23	25	19	24	23	24	26	24
Nb	13	12	19	13	15	15	16	14	14
Zn	108	102	99	77	112	115	144	162	121
Ba	620	740	940	800	800	810	860	860	784
Rb	7	5	9	9	9	11	7	6	7
Sr	880	770	870	900	870	850	860	790	840
V		220	230	240	250	270	260	230	178
Ni	60	83	23	49	49	57	67	47	54
Cr		78	56					51	59
Co				50	49	50	50	49	49
Ta				1.2	1.3	1.4	1.4	1.4	1.4
Sc				21	22	22	23	23	22
Hf				2.3	2.3	2.2	2.6	2.1	2.2
U									
Th					1.1	1.2	1.2	1.4	1.3
La				20	22	25	25	22	23
Ce				48	52	52	53	53	52
Nd				23	17	32	32	28	27
Sm				5.1	5.6	6.6	6.4	5.8	5.9
Eu				2.1	2.6	2.4	2.6	2.3	2.4
Eu/Eu ⁺				1.4	1.7	1.3	1.4	1.3	1.4
Tb				0.60	0.56	0.70	0.81	0.72	0.69
Yb				1.8	1.7	2.2	2.2	1.9	1.9
Lu				0.30	0.27	0.33	0.33	0.29	0.30

¹ Average values from each traverse weighted equally

² FeO (calc) = 0.71 x Fe₂O₃^T (see Fig. 3.7)

³ Total = SiO₂ + TiO₂ + Al₂O₃ + FeO + (Fe₂O₃^T - 1.1113 x FeO) + MgO + CaO + Na₂O + K₂O + P₂O₅ + MnO + LOI
If FeO was not determined then use FeO (calc) instead.

The analyses are not normalized volatile-free to 100% total.

CHAPTER 4

MINERAL CHEMISTRY

4.1 INTRODUCTION

The compositions of the principal rock-forming minerals from a representative suite of samples from the Great Abitibi Dyke (GAD) were analyzed. These data were used to: (1) document the compositional ranges for each mineral type; (2) identify the differences in mineral chemistry between rocks of units 1 and 2; (3) identify chemical covariation between different mineral types; (4) determine equilibrium temperatures for olivine-augite and ilmenite-titanomagnetite mineral pairs; and (5) relate mineral chemistry to the crystallization history of the magma.

4.2 MINERAL CHEMISTRY

4.2.1 Introduction

Feldspars, olivines, augites, titanomagnetites, ilmenites as well as some orthopyroxenes and secondary alteration minerals were analyzed on an electron microprobe using wavelength-dispersive analysis. Details on the analytical procedure are given in Appendix A1.2, and a full listing of the analyses is given in Table A3.1.

The most abundant minerals in rocks of the GAD are plagioclase, olivine, and augite (Fig. 2.6). The essential chemical character of each mineral type can be expressed by the following ratios: plagioclase by $An^* = 100 \cdot Ca / [Ca + Na + K]$, olivine by $Fo^* = 100 \cdot Mg / [Mg + Fe]$ and augite by $En^* = 100 \cdot Mg / [Mg + Fe]$. Molar amounts of each element were

used. Both Fo* and En* are calculated using total iron. As the An*, Fo* and En* of plagioclase, olivine and augite decrease, a magma from which these minerals crystallized tends to become more evolved. In this sense, An*, Fo* and En* can be used to monitor the evolution of the GAD-magma.

4.2.2 Comparison With Other Intrusions

In the GAD, plagioclase ranges in composition from An₆₈ to An₂₀, olivine ranges from Fo₆₈ to Fo₁₀ and augite ranges from En₇₅ to En₄₅ (Fig. 4.1; Table 4.1). This range in mineral composition is comparable to that observed in much larger differentiated mafic/ultramafic bodies. As one example, the Kiglapait Intrusion of Labrador which has a volume of > 1500 km³ contains plagioclase ranging from An₆₇ to An₁₀, olivine from Fo₆₉ to Fo₀, and augite from En₇₃ to En₀ (Morse, 1979). In the still larger Bushveld Complex, South Africa, plagioclase ranges in composition between An₈₀ and An₁₅ and olivine lies between Fo₈₈ and Fo₀ (McBirney, 1984, p. 193).

The observation that the range in mineral chemistry shown by the GAD is comparable to that in these much larger and more slowly cooled intrusions, suggests the GAD magma underwent efficient differentiation. It is remarkable that the full range in mineral chemistry is observed in samples from across the GAD at traverse 7 where the dyke-width is only 220 m.

4.2.3 Feldspar

Feldspar compositions are plotted on an An-Ab-Or (anorthite-

albite-orthoclase) diagram (Fig. 4.2A). The data define a trend that extends from labradorite to oligoclase and finally to anorthoclase. Unit 1 feldspars range between $An_{68}Or_0$ and $An_{20}Or_{10}$ ($An^* = 100 \cdot Ca / [Ca + Na + K]$; $Or^* = 100 \cdot K / [Ca + Na + K]$ in molar amounts), while unit 2 feldspars range between $An_{40}Or_5$ and $An_{20}Or_{40}$.

Most unit 1 rocks contain only one feldspar type, plagioclase. However, some unit 1 samples which contain plagioclase of andesine and oligoclase composition also contain orthoclase (An_5Or_{60}). The presence of two feldspar types, a plagioclase and an orthoclase, is characteristic of evolved basalts. With further evolution, a basaltic liquid produces feldspar compositions along two trends which converge towards the anorthoclase field, plagioclase to anorthoclase and orthoclase to anorthoclase, (Carmichael et al., 1974; Cox et al., 1979, pp. 139-142.). The rocks of unit 2 appear to be the product of highly evolved basaltic liquids, since feldspar compositions are concentrated in the anorthoclase field and high-Na plagioclase fields.

Other minor chemical constituents of the feldspars are Ba and Fe. As the An^* of feldspars decrease (and the GAD-magma becomes more evolved) then the Ba and Fe contents of feldspar are observed to increase and decrease, respectively (Fig. 4.2).

4.2.4 Olivine

Olivine composition ranges from Fo_{68} to Fo_{10} (Fig. 4.3). Most olivines from unit 1 samples have compositions ranging between Fo_{60} and Fo_{30} and most unit 2 samples range between Fo_{35} and Fo_{20} . As the Fo^* decreases, the Si and Mg contents decrease and Fe, Mn and possibly

Ca contents increases. The covariation of SiO_2 , FeO and MgO with Fo^* follows from stoichiometry and the constant sum effect (Chayes, 1971).

As the Fo^* decreases and the magma becomes more evolved, the Mn and perhaps the Ca concentrations (in weight percent) in olivine increase.

4.2.5 Augite

Most unit 1 samples range in composition from En_{75} to En_{55} , while samples from unit 2, range in composition from En_{60} to En_{45} (Fig. 4.4). As En^* decreases Mg, Al, and Ti in augite decrease, Fe and Mn increase and Si, Ca and Na remain approximately constant. The abundances of all of these elements fall within the normal range for augite (Deer et al., 1966) and based on Ti content, the augite in the GAD typically has a composition intermediate between common augite and titanaugite (Deer et al., 1966, p. 120). The covariation of FeO and MgO with En^* follows from stoichiometry.

The weight percent variation in the other elements can be related to the En^* . As the magma evolves and the En^* of augite decreases, the Al and Ti contents of augite decrease, the Mn content of augite increases and the Si, Ca and Na contents of augite remain roughly constant.

4.2.6 Compositional Variation on a Thin-Section Scale

The compositional variation of each mineral phase on the scale of a thin section provides an insight into the crystallization process. The variation is of two types: (1) the variation between the core and

rim compositions of individual grains, i.e. mineral zonation, and (2) the variation between average compositions of different grains.

The range of compositions measured within individual feldspar, olivine and augite grains is presented in Tables 4.2 and 4.3 and Fig. 4.5. The degree of feldspar zoning is highly variable, but is commonly large, i.e. up to 30 (An*). Both normal and reversed zoning are observed. In contrast, olivine grains from the GAD are only weakly zoned, except those adjacent to iron-titanium oxides (see Table 4.2). Augite grains are also only weakly zoned. Weak zoning in olivines and augites may indicate that either (1) the Mg/Fe ratio of the liquid changed little throughout the crystallization history of each grain, or (2) an originally larger degree of zoning was subsequently 'erased' by solid state diffusion during cooling (R. Kretz, pers. comm, 1989).

There is significant inter-grain variation in the composition of mineral species (i.e. augite and olivine) on the scale of a thin section (Appendix 3; Table 4.4). These differences may have been caused by local heterogeneity in the composition of the magma during crystallization.

4.2.7 Accessory Minerals

Some important information is provided by the chemistry of accessory minerals: ilmenite, titanomagnetite, biotite and orthopyroxene (Fig. 4.1; Tables 4.1 and A3.1).

Ilmenites of the GAD have a composition of approximately Ilm₉₇ (along the ilmenite-hematite solid solution series). The composition

of titanomagnetite lies between Usp_{32} and Usp_{66} (along the ulvospinel-magnetite solid solution series).

Biotite from sample RE8401.13 has a TiO_2 content of about 6%, which is consistent with the intense red pleochroic colour (Deer et al., 1966, p. 213) shown by biotites throughout the GAD.

An orthopyroxene grain from a chilled margin sample (traverse 10, sample RE8404.14) has the composition En_{63} (molar $100 \times \text{Mg}/[\text{Mg} + \text{Fe}]$ where $\text{Fe} = \text{Fe}^{3+} + \text{Fe}^{2+}$). Orthopyroxenes in unit 2 samples from traverse 11 (RE8201.03 and RE8201.04) have compositions of En_{33} and En_{29} respectively, and these orthopyroxenes have the same Mg/Fe ratio as coexisting olivines. Small amounts of quartz (mostly in myrmekitic intergrowths with feldspar) are observed in three samples, RE8205.04, RE8201.03 and RE8418.17. The presence of orthopyroxene or quartz indicates silica saturation or over-saturation, respectively. The rare occurrences of orthopyroxene and quartz are probably due to local contamination of the GAD magma by host rocks rich in silica. The presence of these minerals may also be due to alteration.

Alteration minerals present in trace amounts were identified by electron microprobe analysis (Table A3.1). Several samples contain fan-shaped brownish radiating crystals of prehnite and triangular-shaped greenish chamosite (see 'delessite' analysis in Frondel, 1955; Bayliss, 1975) located interstitially between feldspar laths. Elongate, clear grains of pectolite (Deer et al., 1978) occasionally occur within biotite grains. The presence of all three minerals, prehnite, chamosite and pectolite indicates minor hydrothermal alteration.

4.3 ORIGIN OF VARIATION IN MINERAL CHEMISTRY

4.3.1 Fo# of Olivines vs Whole-Rock Ba Content

A plot of olivine composition (expressed as Fo#) vs whole rock Ba abundance yields some useful information about the evolution of the GAD magma. From Fig. 4.6 it can be seen that as olivine becomes increasingly iron-rich, the Ba content of the whole-rock increases.

Assuming that Ba behaved as an incompatible element (Section 3.5), the circled numbers in Fig. 4.6 chart the degree of fractional crystallization as a function of olivine composition. The Ba content of the most primitive chilled margin sample, RE8401.46, is considered to be a reasonable estimate of the Ba content of the parental magma (Section 3.6), and is labelled '0' (i.e. 0% crystallized) in Fig. 4.6.

The range in unit 1 olivine chemistry can be modelled by 0% to 50% fractional crystallization of the assumed parental magma. An additional 20% of fractional crystallization is required in order to produce the olivine compositions of unit 2 samples. This observation allows us to calibrate olivine chemistry in terms of the percentage that the parental magma has crystallized.

The calibration of the data trend is based on the assumption that the samples reflect liquid compositions. The only data from cumulates in Fig. 4.6 are those from samples, RE8401.54, RE8203.13, and RE8401.55, all of which plot near the parental magma composition and, therefore, do not have any role in defining the data-trend.

4.3.2 Olivine and Augite

The $Mg/(Mg+Fe)$ ratios of coexisting augite and olivine define a

linear trend with positive slope (Fig. 4.7). As the olivines become more Fe-rich, the augites also show Fe-enrichment. Furthermore, the data separate into two populations corresponding to samples of unit 1 and unit 2 (Fig. 4.7); unit 2 olivines and augites are typically more iron-rich than those from unit 1.

The relationship between augite chemistry (expressed as $En\#$) and whole-rock Ba content can be inferred from Figs. 4.6 and 4.7. Because the $Mg/(Mg+Fe)$ ratios of augites and olivines are positively correlated, and the $Mg/(Mg+Fe)$ ratio of olivine correlates negatively with whole-rock Ba content (Section 4.3.1), then the $En\#$ of augite must be negatively correlated with whole-rock Ba content.

4.3.3 Olivine-Augite Equilibria

Other bodies, such as the Skaergaard and Kiglapait intrusions have olivines comparable in composition to those of the GAD. Co-existing augites, however, are distinctly more iron-rich than those of the GAD (Fig. 4.8). The high Fe-content of Skaergaard olivines has been attributed to re-equilibration with an Fe-rich intercumulus liquid (Naslund, 1984).

This mechanism is considered unlikely to have operated during the evolution of the GAD because such an Fe-rich intercumulus liquid would need to have (a) affected olivines to a greater degree than augites, (b) had access to all parts of the dyke (both unit 1 and unit 2) and (c) caused greater iron-enrichment towards the dyke interior.

The data in Fig. 4.7 can also be attributed to systematic

variation in equilibrium temperatures. The Mg/Fe distribution between coexisting olivine and augite can be used as a geothermometer (Powell and Powell, 1974; see caveats in Wood, 1976 and Parsons, 1981). Preliminary isotherms were constructed using available experimental and natural data (Fig. 4.9). The 1200° and 550° isotherms were constructed using Ol : Cpx equilibrium data and the 800° isotherm was defined using combined Opx : Cpx and Opx : Ol equilibrium data. Unit 1 data ranges between about 1200° and 800°C and unit 2 samples equilibrated at temperature below 800°C, perhaps as low as 550°. These temperatures can be compared with liquidus and solidus temperatures.

While liquidus and solidus temperatures have not been directly determined for the GAD, they are likely to be comparable to those determined on other gabbroic/basaltic rocks of similar composition. Relevant liquidus and solidus temperatures are available for Hawaiian tholeiitic lavas (Carmichael et al., 1975, pp. 6-7) and from the Klokken Gabbro-Syenite Complex, southern Greenland (Parsons, 1981). The data from Hawaii is applicable to unit 1 rocks while data from the gabbroic and syenitic phases of the Klokken Complex could apply to unit 1 and 2, respectively (Fig. 4.8). Using the data from Hawaii and the Klokken Complex it seems that liquidus and solidus temperatures for the unit 1 magma were probably 1200° and 1000°, respectively, and for unit 2 magma were 950° and 850°, respectively. With respect to the data in Fig. 4.9, it would appear that some unit 1 rocks attained olivine-augite equilibrium between liquidus and solidus temperatures while other unit 1 samples and all unit 2 samples attained augite-

olivine equilibrium at sub-solidus temperatures.

4.3.4 Olivine and Feldspar

The compositions (Fo# and An#) of coexisting olivine and feldspar define a linear trend based mostly on unit 1 data (Fig. 4.10). The unit 2 data (3 samples) all plot at the Ca-poor end of the diagram.

Given the relationship between feldspar and olivine composition and the previously defined relationships between Fo#, En#, Ba content and equilibrium temperature (Sections 4.3.1, 4.3.2 and 4.3.3), it can be inferred that the An# of feldspars in the GAD can be calibrated both in terms of the degree of evolution of the parental magma and also in terms of the temperature of thermal equilibrium.

4.3.5 Titanomagnetite-Ilmenite Equilibria

Oxygen fugacities and equilibrium temperatures were determined for the GAD from coexisting titanomagnetite and ilmenite compositions (Buddington and Lindsley, 1964; Spencer and Lindsley 1981). Temperatures can be determined with an accuracy of $\pm 30^{\circ}\text{C}$ and $f\text{O}_2$ to $\pm$ one log unit (Buddington and Lindsley, 1964).

Ilmenite is present in three forms (Section 2.3.4): (1) ilmenite lamellae within titanomagnetite host grains (2) irregular ilmenite patches within host titanomagnetite grains, and (3) separate homogeneous ilmenite grains probably in equilibrium with the composite titanomagnetite-ilmenite grains (types 1 and 2). The ilmenite in types 1 and 2 may have exsolved from homogeneous titanomagnetite grains at different times and under different conditions of

temperature and oxygen fugacity (e.g. Bowles, 1977).

Most ilmenite analyses were from the ilmenite patches within composite grains while titanomagnetite analyses were taken from texturally homogeneous regions which were distant from all ilmenite lamellae or patches. The data in Fig. 4.11 therefore should yield the equilibrium temperatures and oxygen fugacities for coexisting ilmenite patches and host titanomagnetite grains.

The data in Fig. 4.11 indicate a positive correlation between fO_2 and T with an average temperature of about $700^{\circ}C$ and fO_2 of about 10^{-18} bars (Fig. 4.11). Unit 1 and 2 data overlap. The slightly (but not statistically significant) higher temperatures recorded for samples from traverses 2 and 16 located at the southwest and northeast ends of the dyke may reflect thermal equilibrium at deeper levels and hence higher temperatures (cf. Section 12.3).

The Fe-Ti oxide equilibrium temperatures fall between 650° and $750^{\circ}C$ and are lower than the solidus temperatures estimated for either unit 1 or unit 2 (Sections 4.3.3). The Fe-Ti oxide temperatures probably record the subsolidus temperature at which ilmenite patches exsolved from originally homogeneous titanomagnetite grains.

As compositional equilibrium was reached among the Fe-Ti oxides it appears that fO_2 followed the quartz-fayalite-magnetite (QFM) buffer curve (Fig. 4.11). This data distribution is typical of terrestrial basalts, most of which plot along the QFM buffer curve (BVSP, 1981, pp. 371-375).

4.4 CONCLUSIONS

Unit 1 olivine gabbros contain plagioclase of composition $An_{68-40}Or_{0-10}$, olivine of Fo_{60-30} , and augite of En_{75-55} . Most unit 2 samples, on the other hand, contain olivine of composition Fo_{35-20} , augite of En_{60-45} , and feldspar of $An_{40-20}Or_{5-40}$. In other words, the olivines and augites in unit 2 rocks are more iron-rich, and feldspars more alkali-rich than those contained in unit 1 rocks.

There is a linear correlation between feldspar, olivine and augite chemistry, whole-rock incompatible element (Ba) content, and temperature of chemical equilibrium. All data are consistent with fractional crystallization from a common parental magma. The mineral composition of samples can be calibrated in terms of the degree of evolution of the parental magma and also in terms of equilibrium temperatures. Unit 1 rocks represent 0 - 50% crystallization of the parental magma while unit 2 rocks are formed by 50 - 70% crystallization of the same parental magma. Unit 2 rocks reached chemical equilibration at lower temperatures than unit 1 rocks. Fe-Ti oxide compositions record equilibrium temperatures for subsolidus exsolution of ilmenite patches from originally homogeneous titanomagnetites.

Fig. 4.1: Histograms summarizing the chemistry of olivine, augite, feldspar, titanomagnetite and ilmenite. Data are sample averages of 3 to 17 analyses. Orthoclase analyses from RE8208.04 and RE8418.18 were not used in computing feldspar averages. Data from Table 4.1.

Table 4.1: Average compositions of feldspar, olivine, augite, titanomagnetite, ilmenite, and orthopyroxene

OLIVINE

molar $100 \cdot \text{Mg}/(\text{Mg}+\text{Fe})$ (Fe = total iron)

Sample No.	Traverse No.	Unit No.	N ¹	$\bar{X}$ ²	S ³
RE8428.07	2	1	12	43.4	8.4
RE8428.03	2	1	10	49.7	5.9
RE8203.11	5	2	3	29.2	1.0
RE8203.13	5	1	4	57.9	1.0
RE8401.46	7	1	3	66.2	0.1
RE8401.55	7	1	7	59.8	3.1
RE8401.06	7	1	7	49.3	6.2
RE8401.13	7	2	10	20.2	4.1
RE8401.54	7	1	9	56.1	2.3
RE8401.22	7	2	8	33.2	2.0
RE8401.23	7	1	6	39.6	1.8
RE8401.57	7	2	6	33.8	2.8
RE8401.20	7	2	6	23.5	2.5
RE8401.24	7	1	6	49.1	1.3
RE8401.58	7	1	7	42.4	3.6
RE8401.08	7	2	9	18.7	4.5
RE8401.07	7	1	10	46.6	3.1
RE8404.14	10	1	8	57.1	1.5
RE8201.03	11	2	6	21.9	0.9
RE8201.04	11	2	4	22.8	2.6
RE8207.04	14	1	12	51.7	1.5
RE8207.15	14	2	8	53.8	2.7
RE8418.16	14	2	6	31.8	3.3
RE8418.15	14	2	9	32.4	2.4
RE8418.18	14	1	11	27.6	4.9
RE8418.03	14	1	7	43.7	7.7
RE8208.06	15	1	4	51.4	0.8
RE8208.04	15	1	7	47.1	6.7
RE8208.05	15	1	6	40.0	2.5
RE8208.08	15	1	9	54.8	3.2
RE8209.02	16	1	11	49.9	3.2
RE8209.04	16	1	9	48.6	6.4
RE8209.06	16	1	9	52.6	4.6

¹N = number of measurement per sample

² $\bar{X}$ = mean value

³S = one standard deviation

(Continued on next page)

Table 4.1

FELDSPARmolar $100 \cdot \text{Ca}/(\text{Ca}+\text{Na}+\text{K})$

Sample No.	Traverse No.	Unit No.	N	$\bar{X}$	S
RE8428.07	2	1	17	50.9	15.0
RE8203.13	5	1	4	59.4	5.5
RE8203.11	5	2	9	19.6	9.2
RE8401.07	7	1	10	43.1	10.3
RE8401.06	7	1	15	57.5	10.9
RE8401.08	7	2	15	21.0	13.7
RE8401.46	7	1	7	61.9	4.3
RE8404.14	10	1	11	54.6	6.5
RE8201.04	11	2	10	16.6	13.3
RE8207.07	14	2	5	49.8	6.0
RE8418.18	14	1	14	27.5	14.0
RE8418.18 ⁴	14	1	12	31.6	10.3
RE8418.15	14	2	12	26.1	9.1
RE8208.06	15	1	4	44.3	6.8
RE8208.04	15	1	9	30.7	17.8
RE8208.04 ⁴	15	1	8	34.1	15.4
RE8208.08	15	1	8	55.3	8.9
RE8209.02	16	1	12	40.2	11.8

⁴ Orthoclase analyses excludedAUGITEmolar $100 \cdot \text{Mg}/(\text{Mg}+\text{Fe})$ (Fe = total iron)

Sample No.	Traverse No.	Unit No.	N	$\bar{X}$	S
RE8428.07	2	1	8	66.2	2.9
RE8203.13	5	1	4	67.7	0.6
RE8203.11	5	2	3	56.1	2.3
RE8401.55	7	1	6	70.4	1.7
RE8401.06	7	1	6	67.6	2.7
RE8401.13	7	2	10	57.0	3.4
RE8401.54	7	1	11	69.7	1.5
RE8401.08	7	2	11	56.1	5.7
RE8404.14	10	1	5	71.6	1.3
RE8201.04	11	2	4	57.5	4.2
RE8201.03	11	2	6	58.3	4.3
RE8207.07	14	2	5	59.7	4.8
RE8207.15	14	2	8	66.3	3.5
RE8418.03	14	1	10	64.3	3.2
RE8418.11	14	2	10	48.1	7.5
RE8418.18	14	1	9	59.6	4.5
RE8208.06	15	1	4	65.8	1.1
RE8209.02	16	1	9	68.7	1.4

(Continued on next page)

Table 4.1**TITANOMAGNETITE**molar $100 \cdot \text{Usp} / (\text{Usp} + \text{Mt})$

Sample No.	Traverse No.	Unit No.	N	$\bar{X}$	S
RE8428.03	2	1	5	49.8	3.5
RE8428.07	2	1	5	51.2	3.2
RE8203.13	5	1	4	31.7	3.2
RE8203.11	5	2	5	42.5	5.1
RE8401.24	7	1	4	39.2	3.3
RE8418.15	14	2	3	66.2	6.6
RE8418.18	14	1	3	45.6	3.6
RE8418.16	14	2	5	37.5	3.4
RE8418.03	14	1	3	59.5	1.6
RE8209.04	16	1	4	60.9	4.0

ILMENITEmolar $100 \cdot \text{Ilm} / (\text{Ilm} + \text{Hcm})$

Sample No.	Traverse No.	Unit No.	N	$\bar{X}$	S
RE8428.03	2	1	4	95.10	0.43
RE8428.07	2	1	4	95.11	0.09
RE8203.13	5	1	3	94.31	0.81
RE8203.11	5	2	3	95.27	0.20
RE8401.24	7	1	3	94.72	0.68
RE8418.15	14	2	2	96.55	0.42
RE8418.18	14	1	3	95.87	0.24
RE8418.16	14	2	6	95.27	0.33
RE8418.03	14	1	3	96.27	0.20
RE8209.04	16	1	4	95.92	0.30

ORTHOPYROXENEmolar $100 \cdot \text{Mg} / (\text{Mg} + \text{Fe})$ (Fc = total iron)

Sample No.	Traverse No.	Unit No.	N	$\bar{X}$	S
RE8404.14	10	1	4	62.9	0.8
RE8201.04	11	2	2	29.2	0.6
RE8201.03	11	2	7	33.3	2.4

Fig. 4.2: Feldspar chemistry of the GAD. The $2s$ analytical uncertainty in each graph is no larger than about twice the size of the plot symbols (calculated from estimates of uncertainty in Appendix A1.2 and error propagation equations in Kretz, 1985). (A) Arrow marks the boundary curve which describes the composition of the evolving liquid in equilibrium with both orthoclase and plagioclase. (B) An^* vs FeO_T where $\text{An}^* = \text{molar } 100 \times \text{Ca}/(\text{Ca}+\text{Na}+\text{K}) =$ and FeO_T is total iron expressed as ferrous oxide. (C) An^* vs BaO.

OLIVINES

Fig. 4.3: Olivine chemistry of the GAD. FeO_T is total iron. Horizontal scale equals molar $100 \times \text{Mg}/(\text{Mg} + \text{Fe})$ i.e. $\text{Fo}\%$. $\text{Fe} = \text{Fe}^{2+} + \text{Fe}^{3+}$. The 2s analytical uncertainty in each graph is no larger than about twice the size of the plot symbols (Appendix A1.2).

Fig. 4.4: Augite chemistry of the GAD. FeO_t is total iron. Horizontal scale equals molar $100 \times \text{Mg}/(\text{Mg} + \text{Fe})$ i.e. En#. $\text{Fe} = \text{Fe}^{2+} + \text{Fe}^{3+}$. The 2s analytical uncertainty in each graph is no larger than about twice the size of the plot symbols (Appendix A1.2).

Table 4.2: Relationship between mineral zonation and the adjacent mineral type

Analyzed Mineral	Adjacent Mineral	Difference between core and rim values ¹		
		N	$\bar{X}$	S
Olivine (Fo#):	Fe-Ti Oxide	11	8.56	4.18
	Feldspar	46	2.23	2.93
	Augite	20	0.47	1.67
	Olivine	2	1.47	(range 0.35 to 2.58)
	Biotite	2	5.51	(range 1.94 to 9.07)
	Apatite	1	3.31	
Augite (En#):	Fe-Ti Oxide	5	1.94	1.98
	Feldspar	24	1.24	2.98
	Olivine	16	3.05	4.83
Feldspar (An#):	Not specified	5	0.56	9.36 ²

- ¹ N = number of core minus rim values
 $\bar{X}$ = mean value
S = one standard deviation

- ² In some cases the core is more calcic than the rim and in other cases the core is more sodic.

Table 4.3: Range of feldspar composition in single grains

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Sample	An # Range (Max.-Min.)	Circle #	Grain #	No. of Analyses
8428.07	14.55	1	2	2
8428.07	7.92	100	1	7
8428.07	28.56	2	1	3
8203.13	13.00	1	1	2
8203.13	1.61	2	1	2
8203.11	11.52	3	1	2
8203.11	6.70	4	1	2
8203.11	5.69	4	3	2
8401.06	4.65	6	1	3
8401.08	0.53	7	1	3
8401.08	10.50	8	1	3
8201.04	4.35	1	1	2
8201.04	2.01	1	2	4
8201.04	6.61	1	3	4
8207.07	5.38	1	1	3
8207.07	4.02	2	1	3
8418.18	0.48	6	1	2
8208.06	9.41	1	1	3
8208.04	3.29	4	2	2
8209.02	28.10	200	1	4
8209.02	4.90	3	4	2

$$\text{An \#} = 100 \cdot \text{An} / (\text{An} + \text{Ab} + \text{Or})$$

Fig. 4.5: Typical zoning in plagioclase (from sample RE8428.07) $An^* = \text{molar } 100 \cdot Ca / (Ca + Na + K)$. The 2σ analytical uncertainty in An^* is no larger than about twice the size of the plot symbols.

Table 4.4: Comparison of within- and inter-grain variation in the $Mg^{\#}$ ($100 \cdot Mg / (Mg + Fe)$) of olivines and augites. Data are from Appendix A3.1.

OLIVINE

sample no. RE8428.07	<u>grain 1</u>	<u>grain 2</u>	<u>grain 3</u>
	39 (C)	52 (C)	53 (C)
	32 (*)	51	50
	42		51
	36		49
	32 (*)		34 (*)
sample no. RE8428.03	<u>grain 1</u>	<u>grain 2</u>	<u>grain 3</u>
	57 (C)	53 (C)	46 (C)
	56 (C)	49	47
	57	50	40
			43
sample no. RE8401.55	<u>grain 1</u>	<u>grain 2</u>	<u>grain 3</u>
	63 (C)	56 (C)	61 (C)
	63	56	61
		57	

AUGITE

sample no. RE8428.07	<u>grain 1</u>	<u>grain 2</u>	<u>grain 3</u>	
	63 (C)	68 (C)	69 (C)	
	63	68	69 (C)	
	62	67 (*)		
sample no. RE8401.54	<u>grain 1</u>	<u>grain 2</u>	<u>grain 3</u>	<u>grain 4</u>
	70 (C)	70 (C)	72 (C)	69 (C)
	70 (C)	71	71	70
	70	70		
	70			

(C) = analysis from core of grain; all other analyses are from the rim or from a position intermediate between core and rim.

(*) = rim analysis adjacent to iron-titanium oxide

Fig. 4.6: Plot of whole-rock Ba concentrations and olivine compositions. Each sample is labelled by its traverse number. The plotted data (in order of increasing Fo* in olivines) are: RE8401.08, RE8401.13, RE8201.03, RE8201.04, RE8401.20, RE8418.18, RE8203.11, RE8418.16, RE8418.15, RE8401.22, RE8401.23, RE8428.07, RE8208.05, RE8208.04, RE8209.04, RE8401.24, RE8401.06, RE8428.03, RE8209.02, RE8208.06, RE8209.06, RE8207.15, RE8208.08, RE8401.54, RE8404.14, RE8203.13, RE8401.55, and RE8401.46. The circled numbers mark the degree of fractionation (% liquid crystallized). Cross indicates average $\pm 2s$ analytical uncertainty in the data.

Fig. 4.7: Plot of coexisting olivine and augite compositions. Each sample is coded as unit 1 or unit 2 and is labelled by its traverse number. $\text{Mg}^* = (100 \times \text{Mg}/(\text{Mg} + \text{Fe}))$. These data are in molecular amounts. Sample numbers (in order of increasing Fo^* in olivines) are: RE8401.08, RE8401.13, RE8201.03, RE8201.04, RE8418.18, RE8203.11, RE8428.07, RE8418.03, RE8401.06, RE8209.02, RE8208.06, RE8207.15, RE8401.54, RE8404.14, RE8203.13, RE8401.55. Additional olivine compositions (for which augite compositions were not determined) are included in the histogram; additional data (in order of increasing Fo^*) are from samples RE8418.16, RE8418.15, RE8401.22, RE8401.57, RE8401.23, RE8208.05, RE8401.58, RE8208.04, RE8209.04, RE8401.24, RE8428.03, RE8209.06, RE8208.08, and RE8401.46. All olivine data is included in the histogram. Cross indicates average $\pm 2s$ dispersion about sample averages (determined from the data in Table 4.1).

Fig. 4.8: Comparison of olivine-calcic clinopyroxene compositions from the GAD with those of other gabbroic bodies. Some uncertainty results from differences in the way the $\text{En}^\#$ of calcic clinopyroxene was calculated. In some studies Fe total was used, while in other cases, Fe^{2+} was used. The difference in $\text{En}^\#$ calculated by the two approaches, falls within the $\pm 2\sigma$ spread of the data as given by the cross.

Fig. 4.9: Isotherms for the Mg/(Mg+Fe) compositions of coexisting olivine and calcic-clinopyroxene. The 1200°C data is from Duke (1976). The 800°C curve is determined by combining data for Mg/Fe ratios in coexisting olivine-orthopyroxene (Medaris, 1969) with Mg/Fe ratios of coexisting orthopyroxene-clinopyroxene. The 550°C isotherm is from Obata et al., (1974). The location of the isotherms was determined by R. Kretz (pers. comm., 1989). Isotherms marked with a solid line are well constrained by data. Isotherms marked with a dashed line are speculative. Cross gives an estimated $\pm 2s$ uncertainty in the location of the isotherms.

Fig. 4.10: Plot of coexisting olivine and feldspar compositions. These data are in molecular amounts. Each sample is labelled by its traverse number. Sample numbers (in order of increasing Fo# in olivines) are: RE8401.08, RE8201.04, RE8418.18, RE8203.11, RE8208.05, RE8401.07, RE8428.07, RE8208.04, RE8401.06, RE8209.02, RE8208.06, RE8404.14, RE8203.13, RE8401.46. Orthoclase analyses from RE8208.04 and RE8418.18 were not used in computing feldspar averages. Data from Table 4.1. Cross indicates average $\pm 2s$ dispersion about sample averages (determined from the data in Table 4.1).

Fig. 4.11: Temperature and fO_2 based on composition of coexisting titanomagnetite (Mt_{ss}) and titanilmenites (Ilm_{ss}) in samples of the GAD. Data (from Table 4.1) have been plotted on the diagram devised by Spencer and Lindsley (1981). Numbers beside each data point correspond to the traverse. The QFM (Quartz-Fayalite-Magnetite) buffer is shown. Temperature has units of °C and fO_2 is in bars. Cross gives the uncertainty in temperature and fO_2 as estimated by Buddington and Lindsley (1964)

CHAPTER 5

GEOCHEMICAL MODELLING

5.1 INTRODUCTION

Chemical variation in the Great Abitibi Dyke (GAD) is assumed to be due to liquid-crystal processes whereby crystals are either removed from the magma by fractionation, or concentrated in the magma as cumulates. The minerals involved in these processes can be identified using four complementary approaches: (1) simple numerator-type Pearce ratio diagrams, (2) complex numerator-type Pearce ratio diagrams, (3) normalized Pearce ratio diagrams, and (4) least-squares modelling.

The methodology of least-squares modelling is well established in the literature (Bryan, et al., 1968; Wright and Doherty, 1970) and need not be outlined here, but the theory and use of Pearce ratios is less widely known and will be reviewed. Full details are given in Pearce (1968), Ernst et al. (1988) and Appendix 6.

Pearce ratios are used to remove the constant sum effect which arises from the use of compositional data which sums to 100% (Chayes, 1971). A variation in the percentage abundance of any element must depend in part on variation in the percentage abundances of the other elements, and linear trends can be produced that have little or no geological meaning. Pearce ratios 'open' a data set such that observed trends are solely the consequence of real physical processes.

Pearce ratios are variables of the form A/Z where A and Z are element or oxide abundances. Z is specifically chosen to be an element whose absolute abundance (in units of grams or moles) remains constant

within a system, i.e. is neither added to nor subtracted from the system under investigation. For example, in a system in which only olivine is being removed by fractional crystallization, Zr could be chosen for the denominator variable, Z.

Simple numerator type Pearce ratios use single elements or oxides as the numerator variable, A. Complex numerator-type Pearce ratios use stoichiometric combinations of elements for A (e.g. molar Al+Na-K) in order to focus on the variation produced by the removal (or concentration) of specific minerals. Normalized Pearce ratios are ratios of the simple or complex numerator type, which have been normalized (multiplied) by Z_0 . Z_0 is the abundance of Z in a reference sample usually parental to the suite. Normalized Pearce ratios have the form $[A/Z] \cdot Z_0$.

Pearce ratios can be plotted against each other (e.g. A/Z against B/Z). On such a diagram, called a Pearce ratio diagram, data from a cogenetic suite of samples have a slope equal to the bulk A:B ratio of the mineral assemblage lost from the magma or concentrated from it as a cumulate. A positive slope means that A and B are either both being lost or both being concentrated in the magma. A negative slope means that A is being lost, while B is being concentrated in the magma (or vice versa). Data trends can be evaluated visually using reference mineral vectors which are superimposed on Pearce ratio diagrams and which illustrate the slope that would be expected from removal or concentration of each type of mineral.

Pearce ratios can also be plotted against geographic position in

an igneous body in order to reveal the variation in the absolute abundance of the numerator variable, A, throughout the igneous body.

In order to be a Pearce ratio, the denominator element Z has to have been fixed in absolute abundance as the magma evolves. In the case of the GAD, intersample variation is caused by fractional crystallization and therefore Z should be an incompatible element. Theoretical calculations in Appendix 6 show that even if an element is slightly compatible such that its bulk distribution coefficient reaches 0.1, the error produced on Pearce ratio diagrams is insignificant. The degree of incompatibility of different elements in rocks of the GAD was evaluated in Section 3.5.2. Both La and Ba have sufficiently low distribution coefficients to be used as the denominator variable, Z.

5.2 SIMPLE NUMERATOR-TYPE PEARCE RATIO DIAGRAMS

Simple numerator-type Pearce ratio diagrams (A/Z vs B/Z) were used to determine the bulk composition of the mineral assemblage lost or concentrated as a cumulate during fractionation from the parental magma. Both Ba and La were separately used as the constant denominator variable, Z (Figs. 5.1 and 5.2 and Table 5.1). For the Pearce ratio diagrams in Figs. 5.1 and 5.2, the ordinate (Y-axis) numerator is Si and the abscissa (X-axis) numerator is rotated in turn through all the major elements. Si was chosen for comparison with all other elements because it is the most abundant cation, and because it is a component of most of the major mineral phases which could conceivably

fractionate from the GAD.

Corresponding Pearce ratio diagrams in Figs. 5.1 and 5.2 exhibit similar patterns regardless of whether La or Ba is used as the denominator variable. This is to be expected if the denominator variables are well-chosen.

Silicon content in unit 1 rocks correlates positively with the contents of all other elements except for K and P. The most highly correlated trends in Figs. 5.1 and 5.2 are those in which the abscissa numerator is Al, Mg, Ca, and Na. This requires fractionation of minerals rich in Si, Al, Mg, Ca and Na. In unit 2 rocks (Table 5.1) the elements Al, Ca, Na and K (hosted in feldspar) all show a slight positive correlation with Si. Iron, Mg and Mn (hosted in mafic silicates) as well as P (hosted in apatite) exhibit a weak negative correlation with Si (hosted mainly by feldspar).

On the diagrams where Ti, Fe^{2+} , Fe^{3+} , Mn and P are the abscissa numerator variables, the trend defined by the unit 2 data differs from that defined by the bulk of the unit 1 data. This suggests that the minerals containing, Ti, Fe, Mn and P fractionated in different proportions in the two units.

On the diagrams in which Ti is used as the abscissa numerator variable, some data points fall off the trend defined by the rest of the unit 1 data. These samples are RE8430.03B, RE8401.01, RE8418.12, RE8428.10, RE8203.14, RE8203.15, RE8401.40, RE8203.13, RE8401.53, RE8401.54, and RE8401.55. These samples contain the highest amounts of modal olivine (about 15%) and are identified as cumulates in later

Sections 5.4 and 6.2.4.

5.3 COMPLEX NUMERATOR-TYPE PEARCE RATIO DIAGRAMS

The complex numerators used in Fig. 5.3 are specifically designed to test for fractionation of specific minerals. The method for designing complex numerators is given in Ernst et al. (1988) and Appendix 6. Best-fit slopes were calculated using both Ba and La as the conserved denominator element, Z (Fig. 5.3; Table 5.2).

The complex numerators are designed to discriminate between minerals having ideal stoichiometric compositions, but should effectively discriminate among the minerals which controlled chemical variation in the GAD. For example, the numerator variables in Figs. 5.3A and 5.3B are designed for clinopyroxene of the diopside-hedenbergite solid solution series, but they should also adequately reflect the behaviour of augite.

The relative roles of plagioclase and augite (cpx) fractionation can be assessed using Figs. 5.3A and 5.3B. In both diagrams, the data from samples of unit 1 parallel the plagioclase mineral vector. There is only slight variation in the direction of the augite (cpx) mineral vector. In Fig 5.3A, the variation along the plagioclase vector is about 500 units while that along the augite (cpx) vector is about 50 units. (Note the great difference in scale between the X and Y axes.) This data distribution suggests that plagioclase fractionation is more important than augite fractionation. Data from unit 2 have a significantly different slope which is calculated in Table 5.2. (This

trend in unit 2 data is not visually obvious in Figs. 5.3A and 5.3B because the unit 2 data is compressed into a small region of the diagram). As augite is being removed from the melt some plagioclase is being concentrated (as cumulates) in the melt (or vice versa -- as plagioclase is removed, augite is being concentrated).

The relative contributions of plagioclase, olivine and orthopyroxene fractionation can be assessed from Fig. 5.3C. However, Fig. 5.3D can be used to simplify the interpretation of Fig. 5.3C. In Fig. 5.3D, data from both unit 1 and 2 samples parallel the olivine vector more closely than the orthopyroxene vector suggesting that fractionation of olivine predominated. The trend can in fact be explained by fractionation of olivine alone. This chemical evidence is consistent with the virtual absence of orthopyroxene as a modal phase in the GAD (Table A2.1).

If orthopyroxene fractionation is eliminated, then the orthopyroxene vector can be ignored in Fig. 5.3C and the trend of the data can be entirely attributed to plagioclase and olivine fractionation. The fact that unit 1 data follow a trend intermediate between the olivine and plagioclase reference vectors suggests that both phases were involved in fractionation. The relative contributions of olivine and plagioclase fractionation can be calculated (Table 5.2), and the results indicate that nearly twice as much plagioclase as olivine was fractionated from the original parent magma. Data from unit 2 samples follow a negative slope suggesting loss of plagioclase and accumulation of olivine (or vice versa).

Figs. 5.3A and 5.3B show that augite fractionation had little control on the compositional variation of unit 1 rocks. Therefore, in Fig. 5.3F, the augite mineral vector can be ignored. Only apatite and the anorthite component of plagioclase are potentially responsible for the trends. Variation along the anorthite vector is about 400 units while that along the apatite vector is about 25 units. The slope is closer to that of anorthite than that of apatite which indicates that the variation in both unit 1 and unit 2 chemistry is controlled to a much greater extent by plagioclase than by apatite.

The role of iron-titanium oxides is assessed in Figs. 5.3E, and 5.3I. In designing appropriate complex numerators a composition of Usp_{50} was assigned to the titanomagnetites, and ilmenite was assumed to be pure ilmenite, Ilm_{100} , similar to the compositions of titanomagnetite and ilmenite present in the GAD rocks (Tables 4.1; Fig. 4.1). The data in Figs. 5.3E and 5.3I define a trend with a slope that lies between the slopes of the ilmenite and titanomagnetite (Usp_{50}) reference vectors suggesting that both ilmenite and titanomagnetite were fractionated from the parental liquid in approximately sub-equal proportions.

The complex numerator diagrams can also be used to infer the anorthite content of plagioclase being lost from or concentrated in the melt (Fig. 5.3G). Samples that contain the greatest amount of plagioclase, lie towards the upper right of the diagram and are cumulates. These have a scattered distribution for which a reliable slope could not be defined. The remaining unit 1 data follow a trend

indicating fractionation of plagioclase with a composition of An₆₀₋₇₀ (± 10 , 1s uncertainty). Unit 2 data follow a more scattered trend indicating fractionation of plagioclase of composition An₄₀₋₆₀ (± 10 , 1s uncertainty).

These An#s give the composition of plagioclase removed by fractionation. These An#s tend to be slightly more calcic than the An#s for the plagioclase present in unit 1 and unit 2 rocks (in unit 1, An₄₀₋₇₀ and in unit 2, An₂₀₋₄₀; Chapter 4). This result makes sense because the plagioclase crystallized and removed from a basaltic magma should have a higher An# than later crystallizing plagioclase which was not fractionally removed.

The complex numerator diagrams can also be used to infer the Mg# (molar $100 \times \text{Mg}/(\text{Mg} + \text{Fe})$) value in the olivine and augite being lost from or concentrated in the melt (Fig. 5.3H). As the mineral vectors indicate, the Mg# can potentially be controlled by fractionation of olivine, augite and orthopyroxene, but orthopyroxene fractionation was ruled out for both units (See Fig. 5.3D) and augite fractionation was ruled out for unit 1 rocks (Figs. 5.3A and 5.3B). Therefore, in Fig 5.3H, the unit 1 trend is essentially controlled by olivine, and that of unit 2 data by olivine and augite. In Fig. 5.3H the cumulate samples tend towards higher Pearce ratio values than the remainder of the unit 1 data and have a scattered distribution, for which a reliable slope could not be defined. The bulk of the non-cumulate unit 1 data follow a trend indicating fractionation of olivine with composition Fo₆₀₋₈₀ (± 2 , 1s uncertainty). No augite fractionation was

modelled for unit 1 samples. The unit 2 data follow a different trend from those of unit 1 and have a Mg# between 60 and 30 (± 10 , 1s uncertainty) caused by combined olivine and augite fractionation.

The Mg# for unit 1 and 2 rocks (discussed above) correspond to the compositions of the olivine and augite calculated to have been removed from the melt during fractionation. These compositions tend to be slightly more Mg-rich than the compositions of olivine and augite present in unit 1 and unit 2 rocks (for olivine: Fo₃₀₋₆₀ and Fo₂₀₋₃₅ in units 1 and 2, respectively; for augite: En₆₀₋₄₅ in unit 2 rocks; see Chapter 4). This result makes sense because the olivine and augite being crystallized and lost from a basaltic magma should have higher Mg/Fe ratios (higher Fo# and En#) than later crystallizing olivine and augite which was not fractionally removed.

Table 5.2 summarizes the results of the complex numerator-type Pearce element ratio analysis. Rocks of unit 1 record a history of fractionation dominated by olivine, plagioclase, ilmenite and titanomagnetite. Unit 2 rocks indicate that plagioclase was lost while olivine, augite, ilmenite and titanomagnetite were concentrated (as cumulates) in the magma. The reverse could also be true. In other words, the compositional variation in unit 2 could be explained by redistribution of mineral grains in an essentially closed system.

Another interpretation is possible. Suppose all rocks of unit 2 were derived directly from the unit 1 parental magma rather than from mineral redistribution in a closed system. With respect to the parental magma, the 'mafic' unit 2 rocks could have lost a greater

proportion of plagioclase than mafic minerals while the more 'felsic' unit 2 rocks could have lost a greater proportion of mafic minerals than plagioclase.

One difference between the two models lies in the identification of cumulates. In the redistribution model, all unit 2 rocks could be considered cumulates while in the latter model none are cumulates.

5.4 NORMALIZED PEARCE RATIOS

Normalized Pearce ratios can be used to evaluate mineral losses and accumulation assuming a common parental magma for both unit 1 and 2 rocks. This approach was applied to data from traverse 7. In Fig. 5.4, CIPW normative abundances are plotted against across-dyke position. In Fig. 5.5, these same data are transformed into normalized Pearce ratios of the form $[A/Z] \cdot Z_0$ where A is CIPW abundance, Z equals Ba and Z_0 is given by Ba_0 . Ba_0 is the Ba content in chilled margin sample RE8401.46, considered to represent the composition of the parental magma (Section 3.6).

Uncertainty in the choice of Z_0 does not affect the ratio of normalized Pearce ratios (e.g. $[A/Z] \cdot Z_0 / [B/Z] \cdot Z_0$) since Z_0 cancels out, but will affect the magnitude of normalized Pearce ratios ($[A/Z] \cdot Z_0$). For the case of the GAD, Z_0 is given by a chilled margin sample (RE8401.46) which has a Ba content of 624 ppm. Suppose RE8401.46 had been slightly contaminated by the host rock such that Ba_0 did not equal the Ba content in the parental magma. Furthermore, suppose the amount of contamination could be estimated as ± 75 ppm

(i.e. Ba = 700 or 550 ppm); this corresponds to the range in Ba content in unit 1 samples from traverse 7. The resulting error in the normalized Pearce ratio can be calculated as $\pm 12\%$ (75/624).

Multiplication by Z_0 , in this case by Ba_0 , serves to scale the Pearce ratios in a useful way. The normalized Pearce ratio (NPR) for the parental magma (given by sample RE8401.46 and circled in Fig. 5.5) is given by $NPR_{pl} = 50\%$. A 'typical unit 2 sample' with $NPR_{pl} = 15\%$ can be derived from the parental magma by fractionation of 35% (50%-15%) plagioclase, corresponding to about 2/3 (35%/50%) of the potentially available plagioclase in the parent. Similar calculations, using the normalized Pearce ratios for each CIPW mineral phase enable an estimate to be made of the mineral abundances lost from the parental magma in order to produce any sample of unit 1 or 2.

The 'absolute' titanomagnetite (CIPW magnetite) in dyke margin samples is elevated relative to other unit 1a samples (Figs. 5.4 and 5.5). The explanation for this is uncertain, but may result from host rock contamination such that the Fe^{3+}/Fe^{2+} ratio was increased and more magnetite was formed at the expense of olivine and augite.

Fig. 5.5 shows that rocks of unit 2 (at traverse 7) can be produced by removal of about 40% plagioclase, 6% olivine and 5% ilmenite from the parental magma. Formation of unit 2 magma from the parental magma requires essentially no loss of alkali feldspar (CIPW orthoclase), augite (CIPW diopside), titanomagnetite (CIPW magnetite) or apatite.

The two large spikes located about 30 m in from each margin on

most plots in Fig. 5.5 are thought to be indicative of cumulate rocks. If the normalized Pearce ratio of an evolved interior sample is greater than that of the parental magma, then mineral accumulation must have occurred. The amount of accumulation is given by subtraction of normalized Pearce ratios. These spikes indicate a 10% excess (over the amount in the parental magma) of plagioclase, 6% of augite, 15% of olivine and 3% of ilmenite and also a small excess of titanomagnetite and apatite.

5.5 LEAST-SQUARES MODELLING

The crystallization history of the GAD can also be evaluated using a more traditional approach, i.e. least-squares modelling (Bryan et al., 1969; Wright and Doherty, 1970). The difference between a source (parent) and target (daughter) composition is modelled by simulating the removal of various minerals. Daughter samples from unit 1b and 2 can be produced from the parental magma by plagioclase- and olivine-dominated fractionation (Table 5.3A and B). This observation is consistent with the conclusions drawn from the Pearce ratio diagrams in previous sections.

5.6 PLAGIOCLASE/ZR VS LOG ZR

Fig. 5.6 displays the variation between a Pearce ratio diagnostic of plagioclase ($[\text{Al}_2\text{O}_3 + \text{Na}_2\text{O} - \text{K}_2\text{O}]/\text{Zr}$) and a linear measure of the degree of fractionation of the liquid (given by $\log \text{Zr}$). The inverse correlation shown in Fig. 5.6 shows that as the magma becomes more evolved (increasing $\log \text{Zr}$), the amount of 'potential' plagioclase

component in the liquid decreases, a consequence of plagioclase fractionation. Those unit 1 samples with larger Plagioclase/Zr values than the parental magma (RE8401.46) are plagioclase cumulates. Most of these plagioclase cumulates are samples of unit 1 from near the contact with unit 2.

The range of compositions shown by the chilled margin samples from traverses 7, 10, 14 and 15 overlap with more than half of the range of the non-cumulate unit 1 samples. This range in composition corresponds to ~30% crystallization of the magma (Fig. 5.6). This range in crystallization cannot have occurred after magma injection because chilled margin chemistry is "frozen in" as soon as the magma arrives. Therefore, any heterogeneity must result from fractional crystallization either during the process of magma injection, or in an external magma chamber prior to emplacement.

5.7 CONCLUSIONS

Modelling of the whole-rock chemistry using Pearce ratios has revealed that fractionation of plagioclase and olivine are mainly responsible for inter-sample variation in both unit 1 and 2 rocks. In rocks of unit 2, augite fractionation also becomes important. Unit 2 rocks can be derived from the parental magma by 50 to 70% fractionation of mainly plagioclase and olivine in varying relative proportions. Some unit 1 rocks are cumulates.

Fig. 5.1: Pearce ratio diagrams of major element data using La as the denominator variable. Arrows are reference mineral vectors. Molar abundances were used in calculating ratios. Quantitative analysis of the data is given in Table 5.1. The 2s analytical error is no more than approximately three times the size of the plot symbol; it is worst for the plots with minor element numerators.

Fig. 5.1

(Continued on next page)

Fig. S.1

Fig. 5.2: Pearce ratio diagram of major element data using Ba as the denominator variable. Arrows are reference mineral vectors. Molar abundances were used. Quantitative analysis of the data is given in Table 5.1. The 2s analytical error is no more than approximately twice the size of the plot symbol.

- SATELLITE DYKES (UNIT 1)
- △ MARGIN OF MAIN DYKE (UNIT 1)
- ▽ CUMULATES ('); BAKITTI < 800 PPM (UNIT 1)
- ◻ REMAINING SAMPLES OF UNIT 1
- ◆ UNIT 2

(Continued on next page)

Fig. 5.2

(Continued on next page)

Fig. 5.2

Table 5.1: Pearce ratios of major element oxides used to calculate the composition of the mineral assemblage responsible for inter-sample variation. For samples related by fractional crystallization, the 'mineral assemblage' is the fractionate. For cumulates, the 'mineral assemblage' consists only of the cumulus minerals. The slope¹ on Pearce ratio plots of the form A/La vs Si/La and A/Ba vs Si/Ba equals the A:Si ratio in the 'mineral assemblage' (denoted ^{*}A/^{*}Si). 'A' represents each of the major elements in turn and La and Ba are incompatible elements. S means standard deviation. R is correlation coefficient.

A UNIT 1 AND UNIT 2

N=51

A	S(A/La)	R	SLOPE ON PEARCE RATIO DIAGRAM ¹		COMPOSITION OF MINERAL ASSEMBLAGE		COMPOSITION OF MINERAL ASSEMBLAGE		
			[*] A/ [*] Si	S([*] A/ [*] Si)	mole %	S([*] A)	wt%	[*] A	S([*] A)
			x 100	x 100	[*] A ²	S([*] A) ³			
Si	15886	1.000	100.0	0.000	41.20	0.35	SiO ₂	44.42	0.41
Ti	976	0.839	6.1	0.464	2.51	0.19	TiO ₂	3.60	0.26
Al	8702	0.992	54.8	0.986	22.58	0.36	Al ₂ O ₃	20.65	0.31
Fe ²⁺	2631	0.916	16.6	0.930	6.84	0.36	FeO	8.82	0.43
Fe ³⁺	707	0.906	4.5	0.266	1.85	0.11	Fe ₂ O ₃	2.66	0.15
Mg	4097	0.935	25.8	1.290	10.63	0.48	MgO	7.69	0.33
Ca	3497	0.981	22.0	0.594	9.06	0.23	CaO	9.12	0.23
Na	1997	0.973	12.6	0.416	5.19	0.07	Na ₂ O	2.89	0.09
K	247	0.703	1.6	0.160	0.66	0.06	K ₂ O	0.56	0.06
P	187	-0.390	-1.2	0.154	-0.49	0.09	P ₂ O ₅	-0.63	0.08
Mn	43	0.893	0.3	0.019	0.12	0.01	MnO	0.16	0.01
Total					100.00			100.00	
Fe ³⁺ +T	3325	0.918	20.9	1.170	8.61	0.49	Fe ₂ O ₃ T	12.34	0.71

N=163

A	S(A/Ba)	R	SLOPE ON PEARCE RATIO DIAGRAM		COMPOSITION OF MINERAL ASSEMBLAGE		COMPOSITION OF MINERAL ASSEMBLAGE		
			[*] A/ [*] Si	S([*] A/ [*] Si)	mole %	S([*] A)	wt%	[*] A	S([*] A)
			x 100	x 100	[*] A ²	S([*] A) ³			
Si	352	1.000	100.0	0.000	39.02	0.27	SiO ₂	42.08	0.32
Ti	23	0.655	6.5	0.384	2.54	0.15	TiO ₂	3.64	0.20
Al	199	0.978	56.6	0.906	22.08	0.31	Al ₂ O ₃	20.20	0.26
Fe ²⁺	68	0.820	19.2	0.864	7.49	0.32	FeO	9.66	0.37
Fe ³⁺	20	0.563	5.6	0.364	2.18	0.14	Fe ₂ O ₃	3.13	0.20
Mg	114	0.911	32.3	1.033	12.60	0.36	MgO	9.12	0.24
Ca	85	0.969	24.2	0.460	9.44	0.17	CaO	9.50	0.17
Na	41	0.957	11.6	0.267	4.53	0.10	Na ₂ O	2.52	0.06
K	6	-0.058	-1.7	0.132	-0.66	0.05	K ₂ O	-0.56	0.04
P	8	-0.157	-2.2	0.169	-0.86	0.07	P ₂ O ₅	-1.09	0.08
Mn	1	0.759	0.3	0.015	0.12	0.01	MnO	0.15	0.01
Total					100.00			100.00	
Fe ³⁺ +T	82	0.814	23.3	1.072	9.09	0.42	Fe ₂ O ₃ T	13.03	0.61

(Continued on next page)

Table 5.1

B UNIT 1

N=45

A	S(A/La)	R	SLOPE ON PEARCE RATIO DIAGRAM		COMPOSITION OF MINERAL ASSEMBLAGE		COMPOSITION OF MINERAL ASSEMBLAGE	
			$\frac{A}{Si}$	$S(\frac{A}{Si})$	mole %		wt%	
			$\times 100$	$\times 100$	A	S(A)	A	S(A)
Si	14894	1.000	100.0	0.000	41.44	0.38	SiO ₂	44.61 0.43
Ti	919	0.812	6.2	0.539	2.57	0.22	TiO ₂	3.68 0.30
Al	7983	0.991	53.6	1.072	22.21	0.39	Al ₂ O ₃	20.28 0.33
Fe ²⁺	2533	0.929	17.0	0.935	7.05	0.37	FeO	9.07 0.43
Fe ³⁺	677	0.923	4.5	0.261	1.86	0.11	Fe ₂ O ₃	2.67 0.15
Mg	3914	0.933	26.3	1.424	10.90	0.53	MgO	7.87 0.36
Ca	3189	0.981	21.4	0.621	8.87	0.25	CaO	8.91 0.24
Na	1789	0.971	12.0	0.432	4.97	0.18	Na ₂ O	2.76 0.10
K	243	0.737	1.6	0.162	0.66	0.07	K ₂ O	0.56 0.06
P	185	-0.439	-1.2	0.160	-0.50	0.07	P ₂ O ₅	-0.63 0.08
Mn	42	0.917	0.3	0.018	0.12	0.01	MnO	0.16 0.01
Total					100.00			100.00
Fe ³⁺ +T	3194	0.932	21.4	1.156	8.87	0.49	Fe ₂ O ₃ T	12.69 0.71

N=121

A	S(A/Ba)	R	SLOPE ON PEARCE RATIO DIAGRAM		COMPOSITION OF MINERAL ASSEMBLAGE		COMPOSITION OF MINERAL ASSEMBLAGE	
			$\frac{A}{Si}$	$S(\frac{A}{Si})$	mole %		wt%	
			$\times 100$	$\times 100$	A	S(A)	A	S(A)
Si	268	1.000	100.0	0.000	37.92	0.41	SiO ₂	40.83 0.48
Ti	19	0.324	7.1	0.611	2.69	0.23	TiO ₂	3.86 0.32
Al	149	0.955	55.8	1.507	21.16	0.49	Al ₂ O ₃	19.33 0.41
Fe ²⁺	56	0.777	21.0	1.197	7.96	0.42	FeO	10.25 0.50
Fe ³⁺	20	0.419	7.4	0.614	2.81	0.23	Fe ₂ O ₃	4.02 0.32
Mg	100	0.862	37.3	1.716	14.14	0.57	MgO	10.22 0.38
Ca	63	0.942	23.4	0.725	8.87	0.27	CaO	8.92 0.26
Na	30	0.922	11.3	0.396	4.29	0.15	Na ₂ O	2.38 0.09
K	6	-0.040	-2.4	0.218	-0.91	0.08	K ₂ O	-0.77 0.07
P	8	-0.139	-3.0	0.270	-1.14	0.10	P ₂ O ₅	-1.45 0.13
Mn	1	0.722	0.4	0.025	0.15	0.01	MnO	0.19 0.01
Total					100.00			100.00
Fe ³⁺ +T	68	0.759	25.5	1.504	9.67	0.58	Fe ₂ O ₃ T	13.84 0.84

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Table 5.1

C UNIT 2

N=6

SLOPE ON PEARCE RATIO DIAGRAM				COMPOSITION OF MINERAL ASSEMBLAGE					
A	S(A/La)	R	A/Si	S(A/Si)	mole %		wt%		
			x 100	x 100	A	S(A)	A	S(A)	
Si	4853	1.000	100.0	0.000	50.35	2.31	SiO ₂	56.87	2.07
Ti	271	-0.715	-5.6	1.596	-2.82	0.81	TiO ₂	-4.23	1.23
Al	3084	0.944	63.5	8.573	31.97	2.98	Al ₂ O ₃	30.63	2.16
Fe ²⁺	1208	-0.746	-24.9	6.772	-12.54	3.46	FeO	-16.93	4.72
Fe ³⁺	374	-0.742	-7.7	2.109	-3.88	1.08	Fe ₂ O ₃	-5.82	1.63
Mg	830	-0.798	-17.1	4.206	-8.61	2.15	MgO	-6.53	1.65
Ca	271	0.831	5.6	1.271	2.82	0.64	CaO	2.97	0.66
Na	1156	0.958	23.8	2.785	11.98	1.34	Na ₂ O	6.98	0.78
K	279	0.966	5.7	0.604	2.87	0.32	K ₂ O	2.54	0.30
P	212	-0.849	-4.4	0.950	-2.22	0.49	P ₂ O ₅	-2.96	0.66
Mn	24	-0.726	-0.5	0.140	-0.25	0.07	MnO	-0.34	0.10
Total					100.00			100.00	
Fe ³⁺ +T	1580	-0.746	-32.6	8.867	-16.41	4.53	Fe ₂ O ₃ T	-24.64	6.87

N=42

SLOPE ON PEARCE RATIO DIAGRAM				COMPOSITION OF MINERAL ASSEMBLAGE					
A	S(A/Ba)	R	A/*Si	S(*A/*Si)	mole %		wt%		
			x 100	x 100	A	S(*A)	A	S(*A)	
Si	62	1.000	100.0	0.000	42.12	1.57	SiO ₂	47.70	1.62
Ti	10	-0.109	-15.8	2.417	-6.66	1.05	TiO ₂	-10.02	1.61
Al	47	0.777	76.0	7.372	32.01	2.21	Al ₂ O ₃	30.75	1.66
Fe ²⁺	45	-0.183	-72.4	11.004	-30.50	4.77	FeO	-41.29	6.60
Fe ³⁺	11	-0.101	-17.8	2.741	-7.50	1.19	Fe ₂ O ₃	-11.28	1.83
Mg	22	-0.076	-36.0	5.544	-15.16	2.40	MgO	-11.52	1.86
Ca	18	0.336	28.3	4.104	11.92	1.57	CaO	12.60	1.50
Na	17	0.791	26.7	2.510	11.25	1.02	Na ₂ O	6.57	0.60
K	4	0.744	6.4	0.659	2.70	0.29	K ₂ O	2.39	0.26
P	6	-0.088	-10.2	1.570	-4.30	0.68	P ₂ O ₅	-5.75	0.93
Mn	1	-0.153	-1.3	0.197	-0.55	0.09	MnO	-0.73	0.12
Total					100.00			100.00	
Fe ³⁺ +T	53	-0.175	-85.7	13.032	-36.10	5.65	Fe ₂ O ₃ T	-54.32	8.69

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Table 5.1**Notes on Table 5.1**

¹ Best-fitting slopes are calculated using the 'reduced major axis' method discussed in York (1966). According to this method the slope equals:

$$\text{SLOPE} = S_Y/S_X (1 \pm [(1-R^2)/N]^{0.5})$$

where S_Y and S_X are the standard deviations of the Pearce ratios, R is the correlation coefficient between pairs of Pearce ratios, and N is the number of data points used.

² $A_i = (A_i/Si) / T$ where A_i = all the elements in turn

For Unit 1 data and combined unit 1 and 2 data (Sections A and B):

$$T = Si/Si + Ti/Si + Al/Si + Fe^{2+}/Si + Fe^{3+}/Si + Mg/Si + Ca/Si + Na/Si + Mn/Si$$

For Unit 2 data (Section C):

$$T = Si/Si + Al/Si + Ca/Si + Na/Si + K/Si$$

³ Two error propagation equations were used (Kretz, 1985):

$$\text{Let } U = X/(X+Y) \text{ then } S_u = (Y^2 S_Y^2 + X^2 S_X^2)^{0.5} / (X + Y)^2 \quad (1)$$

$$\text{Let } U = X/Y \text{ then } S_u = U(S_X^2/X^2 + S_Y^2/Y^2)^{0.5} \quad (2)$$

For the unit 1 and combined units 1 and 2 data

Y equals the sum of Si, Ti, Al, Fe^{2+} , Fe^{3+} , Mg, Ca, Na and Mn data.

Equation 1 is used for X = Si, Ti, Al, Fe^{2+} , Fe^{3+} , Mg, Ca, Na and Mn data

Equation 2 is used for X = K, P and Fe_{tot} data.

For the unit 2 data alone, then

Y equals the sum of Si, Al, Ca, Na and K data.

Equation 1 is used for X = Si, Al, Ca, Na and K data.

Equation 2 is used for Ti, Fe^{2+} , Fe^{3+} , Mg, P, Mn, Fe_{tot} data.

Fig. 5.3: Pearce ratio diagram using complex numerators designed to test for fractionation of particular mineral phases and to determine the proportions of these phases in the fractionate. Arrows are reference mineral vectors. In H the "2xOl" written adjacent to the mineral vectors means that on the basis of stoichiometry, olivine (Ol) is twice as effective in controlling the data-slope as is clinopyroxene (Cpx) or orthopyroxene (Opx). Data symbols are the same as in Fig. 5.2. Molar abundances were used. Quantitative analysis of the data is given in Table 5.2. The 2s analytical error is no more than approximately three times the size of the plot symbol.

Fig. 5.3

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Fig. 5.3

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Fig. 5.3

Table 5.2: Pearce ratios with complex numerators used to identify the minerals and their abundances responsible for inter-sample variation.

A

Unit 1 and 2.

Divisor is Ba

N=163

Interpretation of slope
(See Fig. 5.3)

Pearce Ratio Diagram ¹	Pearce Ratio Diagram ¹		Mineral Ratios ²	Ratios		Composition ⁴
	Slope	$\frac{R}{S}$		$\frac{X}{100}$	$\frac{S}{100}$	
Cpx:Pl	0.143	0.258	Pl:Pl	100.00	0.00	Plagioclase
(Cpx+Pl): Pl	1.046	0.991	Cpx:Pl	14.30	1.09	Augite
Ol:Pl	0.607	0.823	Ol:Pl	60.70	2.67	Olivine
(Opx+Ol) : (Ol +0.5•Opx)	1.128	0.881	Ilm:Pl	13.14	1.65	Ilmenite
(Ilm+Usp50): Usp50	2.319	0.757	Ap:Pl	-0.20	2.90	Apatite
Ap:(An+5•Ap)	-0.030	-0.012	An# (Pl)	66.35	5.72	Usp50
Ab:An	0.507	0.931	Mg# (Ol)	72.00	1.91	K-Feldspar
Mg:Fe ²⁺ (in olivines)	2.571	0.777	Usp50:Pl	4.98	0.62	An#
2•Usp50:Fe ²⁺	0.293	0.650	Kfs:Pl	-0.05	0.38	Mg#
K:Pl	-0.049	-0.097				

Unit 1 and 2

Divisor is La

N=51

Interpretation of slope
(See Fig. 5.3)

Pearce Ratio Diagram	Pearce Ratio Diagram		Mineral Ratios	Ratios		Composition
	Slope	$\frac{R}{S}$		$\frac{X}{100}$	$\frac{S}{100}$	
Cpx:Pl	0.094	0.561	Pl:Pl	100.00	0.00	Plagioclase
(Cpx+Pl): Pl	1.056	0.997	Cpx:Pl	9.40	1.09	Augite
Ol:Pl	0.463	0.877	Ol:Pl	46.3	3.10	Olivine
(Opx+Ol) : (Ol +0.5•Opx)	1.235	0.917	Ilm:Pl	9.54	1.02	Ilmenite
(Ilm+Usp50): Usp50	2.760	0.916	Ap:Pl	-1.12	3.50	Apatite
Ap:(An+5•Ap)	-0.018	-0.254	An# (Pl)	62.23	5.77	Usp50
Ab:An	0.607	0.969	Mg# (Ol)	78.23	1.50	K-Feldspar
Mg:Fe ²⁺ (in olivines)	3.594	0.924	Usp50:Pl	2.71	0.32	An#
2•Usp50:Fe ²⁺	0.269	0.976	Kfs:Pl	4.7	0.48	Mg#
K:Pl	0.047	0.686				

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Table 5.2

B

Unit 1

Divisor is Ba

N=121

Interpretation of slope
(See Fig. 5.3)

Pearce Ratio Diagram Slope	R	S	Mineral Ratios Pl:Pl	Cpx:Pl	Ol:Pl	Ilm:Pl	Ap:Pl	An# (Pl)	Mg# (Ol)	Usp50:Pl	Kfs:Pl	Ratios		Composition mole%		S
												X 100	X 100	Plagioclase	Augite	
Cpx:Pl	0.185	0.033	0.01684									100.00	0.00	45.96	8.50	1.22
(Cpx+Pl): Pl	1.023	0.984	0.01637									18.50	1.68	34.93	6.87	0.81
Ol:Pl	0.760	0.761	0.04484									76.00	4.48	1.33	2.26	1.37
(Opx+Ol) : (Ol +0.5•Opx)	1.193	0.840	0.05846									14.95	2.96	3.74	2.11	0.62
(Ilm+Usp50): Usp50)	1.919	0.680	0.12857									2.89	4.60	-3.26	0.31	0.31
Ap:(An+5•Ap)	0.043	0.049	0.00391									67.20	9.43	67.20	9.43	9.43
Ab:An	0.488	0.863	0.02245									69.50	2.54	69.50	2.54	2.54
Mg:Fe ²⁺ (in olivines)	2.279	0.768	0.13218									8.13	1.33			
2•Usp50:Fe ²⁺	0.351	0.514	0.02738									-7.10	0.64			
K:Pl	-0.071	-0.120	0.00639													

Unit 1

Divisor is La

N=45

Interpretation of slope
(See Fig. 5.3)

Pearce Ratio Diagram Slope	R	S	Mineral Ratios Pl:Pl	Cpx:Pl	Ol:Pl	Ilm:Pl	Ap:Pl	An# (Pl)	Mg# (Ol)	Usp50:Pl	Kfs:Pl	Ratios		Composition mole%		S
												X 100	X 100	Plagioclase	Augite	
Cpx:Pl	0.099	0.525	0.01257									100.00	0.00	57.91	5.73	1.35
(Cpx+Pl): Pl	1.055	0.997	0.01256									9.90	1.26	28.67	2.20	0.74
Ol:Pl	0.495	0.873	0.03614									49.5	3.61	5.95	0.73	0.73
(Opx+Ol) : (Ol +0.5•Opx)	1.310	0.936	0.06943									10.28	1.24	-0.69	2.26	2.26
(Ilm+Usp50): Usp50)	2.715	0.900	0.17648									-1.19	3.90	1.74	0.22	0.22
Ap:(An+5•Ap)	-0.019	-0.313	0.00270									62.89	6.61	2.95	0.31	0.31
Ab:An	0.590	0.966	0.02301									77.32	1.61	62.89	6.61	6.61
Mg:Fe ²⁺ (in olivines)	3.409	0.930	0.18750									3.00	0.38	77.32	1.61	1.61
2•Usp50:Fe ²⁺	0.267	0.971	0.00961									5.10	0.53			
K:Pl	0.051	0.717	0.00530													

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Table 5.2

C

Unit 2

Divisor is Ba

N=42

Interpretation of slope
(See Fig. 5.3)

Pearce Ratio Diagram Slope	R	S	Mineral Ratios Pl:Pl	Ratios X 100 100.00	S X 100 0.00	Composition mole%	S
Cpx:Pl	-0.490	-0.730	0.05145			Plagioclase	88.18
(Cpx+Pl): Pl	0.724	0.887	0.05140			Augite	-43.21
Ol:Pl	-0.611	-0.637	0.07271			Olivine	-53.88
(Opx+Ol) : (Ol +0.5•Opx)	1.441	0.717	0.15563			Ilmenite	-11.80
(Ilm+Usp50): Usp50)	1.782	0.827	0.15503			Apatite	5.19
Ap:(An+5•Ap)	0.121	0.772	0.01186			Usp50	-7.55
Ab:An	1.054	0.674	0.12016			K-Feldspar	11.82
Mg:Fe ²⁺ (in olivines)	0.749	0.759	0.07565			An#	48.69
2•Usp50:Fe ²⁺	0.245	0.698	0.02720			Mg#	42.82
K:Pl	0.134	0.756	0.01353				13.48

Unit 2

Divisor is La

N=6

Interpretation of slope
(See Fig. 5.3)

Pearce Ratio Diagram Slope	R	S	Mineral Ratios Pl:Pl	Ratios X 100 100.00	S X 100 0.00	Composition mole%	S
Cpx:Pl	-0.193	-0.823	0.04478			Plagioclase	87.64
(Cpx+Pl): Pl	0.848	0.992	0.04494			Augite	-16.91
Ol:Pl	-0.260	-0.953	0.03198			Olivine	-22.79
(Opx+Ol) : (Ol +0.5•Opx)	2.562	0.690	0.75579			Ilmenite	-2.57
(Ilm+Usp50): Usp50)	1.448	0.993	0.07240			Apatite	-9.57
Ap:(An+5•Ap)	-0.261	-0.449	0.09527			Usp50	-2.87
Ab:An	1.390	0.986	0.09452			K-Feldspar	12.36
Mg:Fe ²⁺ (in olivines)	1.455	0.988	0.09021			An#	41.84
2•Usp50:Fe ²⁺	0.309	0.992	0.01607			Mg#	59.27
K:Pl	0.141	0.986	0.00973				4.26

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Table 5.2

Notes on Table 5.2

¹ Best-fit slopes and uncertainties are calculated using the 'reduced major axis' method discussed in York (1966). According to this method, the slope equals:

$$\text{SLOPE} = S_Y/S_X (1 \pm (1-R^2)/N)^{0.5}$$

where S_Y and S_X are the standard deviations of the Pearce ratios, R is the correlation coefficient between pairs of Pearce ratios and N is the number of data points used.

$$2\text{Ilm}/\text{Pl} = \{(\text{Ilm} + \text{Usp50})/\text{Usp50} - 1\} \{2\text{Usp50}/\text{Fc}^{2+}\} \{1/(1 + \text{Mg}/\text{Fc}^{2+})\} \{2\} \{ \text{Ol}/\text{Pl} \}$$

$$\text{Ap}/\text{Pl} = \{ \text{Ap}/\text{An} \} \{ 1/(1 + \text{Ab}/\text{An}) \} - \{ \text{Ap}/(\text{An} + 5\text{Ap}) \} \{ 1/(1 + \text{Ab}/\text{An}) \}$$

$$\text{Usp50}/\text{Pl} = \{ 1/2 \} \{ 2\text{Usp50}/\text{Fc}^{2+} \} \{ 1/(1 + \text{Mg}/\text{Fc}^{2+}) \} \{ 2 \} \{ \text{Ol}/\text{Pl} \}$$

$$\text{An}\# = 100 \{ 1/(1 + \text{Ab}/\text{An}) \}$$

$$\text{Mg}\# = 100 \{ 1 - (1/(1 + \text{Mg}/\text{Fc})) \}$$

It is assumed that Mg/Fc ratio in olivine is approximately the same as in augite.

³ Error propagation follows Kretz (1985).

⁴ The abundance of each mineral, A_i , is given as A/T where T equals total. For combined unit 1 & 2 (A) and unit 1 (B) groups:

$$T = \text{Pl}/\text{Pl} + \text{Cpx}/\text{Pl} + \text{Ol}/\text{Pl} + \text{Usp50}/\text{Pl} + \text{Ilm}/\text{Pl}$$

For unit 2 (C) group:

$$T = \text{Pl}/\text{Pl} + \text{Kfs}/\text{Pl}$$

Fig. 5.4: CIPW normative abundance (wt%) vs position across the dyke at traverse 7. Short vertical solid lines locate the boundary between units 1 and 2.

TRAVERSE 7

Fig. 5.5: Normalized Pearce ratios (in wt%) vs position across the dyke at traverse 7. These normalized Pearce ratios are calculated using CIPW normative abundances and Ba content. Ba_0 is from the reference sample, RE8401.46 (Section 3.6), which is circled. Short vertical solid lines locate the boundary between units 1 and 2.

TRAVERSE 7

Table 5.3: Least-squares mixing calculations designed to test the fractionation model determined using Pearce ratio diagrams. Modelling was done using the computer program of Geist et al. (1985). (A) Derivation of a unit 1b sample, RE8401.23 from the parental magma given by sample RE8401.46. Both RE8401.23 and RE8401.46 are from traverse 7. (B) Derivation of a unit 2 sample, RE8418.01, from the parental magma given by sample, RE8401.46. RE8418.01 is from traverse 14.

A

	PARENT (RE8401.46)	DAUGHTER (RE8401.23)	CALCULATED DAUGHTER	RESIDUALS
SiO ₂	45.19	44.26	44.25	0.00
TiO ₂	3.51	5.82	5.82	0.00
Al ₂ O ₃	17.07	13.43	13.47	0.04
FeO _T	13.44	16.52	16.52	0.00
MnO	0.18	0.22	0.17	0.05
MgO	6.77	4.73	4.74	0.01
CaO	9.23	9.28	9.29	0.01
Na ₂ O	2.95	3.43	3.14	0.29
K ₂ O	0.65	1.28	1.53	0.26

SOLUTION:

100% Parent -- 68.0% Minerals (removed) = 32.0% Daughter

100% Minerals (removed)¹ = 63.7% Pl + 24.8% Ol + 6.6% Cpx +
0.3% TiMt + 4.6% Ilm

Sum of squares of residuals = 0.16

B

	PARENT (RE8401.46)	DAUGHTER (RE8418.01)	CALCULATED DAUGHTER	RESIDUALS
SiO ₂	45.19	54.45	54.28	0.17
TiO ₂	3.51	2.09	2.09	0.00
Al ₂ O ₃	17.07	18.63	18.77	-0.14
FeO _T	13.44	7.83	7.82	0.01
MnO	0.18	0.14	0.04	0.10
MgO	6.77	1.56	1.78	-0.22
CaO	9.23	7.04	7.28	-0.25
Na ₂ O	2.95	4.91	5.22	-0.32
K ₂ O	0.65	2.33	3.17	-0.83

SOLUTION:

100% Parent -- 84.9% Minerals (removed) = 15.0% Daughter

100% Minerals (removed)¹ = 56.2% Pl + 21.3% Ol + 13.2% Cpx +
2.9% TiMt + 6.5% Ilm

Sum of squares of residuals = 0.97

¹ Mineral compositions are from sample RE8203.13 (Table A3.1)

Fig. 5.6: Plot of log Zr vs plagioclase/Zr. The abundance of plagioclase is calculated as molar $\text{Al}_2\text{O}_3 + \text{Na}_2\text{O} - \text{K}_2\text{O}$. Symbols are the same as in Fig. 5.1. The cross indicates the average $\pm 2s$ analytical uncertainty. The location of the data point corresponding to dyke-margin sample, RE8401.46, is indicated. The other chilled margin samples arranged in order of increasing Zr abundance are (Table 3.6): RE8207.04, RE8404.14, RE8207.03, RE8207.05, RE8208.09, RE8207.01, and RE8404.13.

CHAPTER 6

REGIONAL COMPOSITIONAL VARIATION

6.1 INTRODUCTION

The Great Abitibi Dyke (GAD) shows systematic regional variation in composition (Appendix 7 and Fig. 6.1). The most prominent variation is between unit 1 and unit 2 rocks. Unit 1 rocks are found throughout the dyke while unit 2 rocks are present along the interior of the dyke extending along about half of the dyke length. There is systematic regional variation within each unit. Both across-dyke and along-dyke variation occurs and this variation is documented and modelled in this chapter. As well the compositional differences between the two units are explained.

6.2 ACROSS-DYKE VARIATION

6.2.1 Chemical Asymmetry Across the Dyke

At traverse 7, the chemical composition of unit 2 rocks change in an asymmetrical manner across the dyke (Fig. 6.2). Barium, K, Na, Si and Sr contents tend to be higher on the south side while Ca, Mg, Ti, P, Y, Zn and, to a lesser degree, Fe concentrations are higher on the north side. Niobium and Zr abundances are erratic across the width of unit 2, but no overall trend is observed. These variations can be correlated with specific minerals. Barium, K, Si, Na and Sr can be correlated with feldspar, Y and P with apatite, Zn with titanomagnetite and Mg, Ti, Ca and Fe, with olivine, augite, ilmenite, and titanomagnetite (Carmichael et al., 1974, p. 279). The variation

illustrated in Fig. 6.2 suggests that the abundances of olivine, augite, ilmenite, titanomagnetite and apatite decrease while feldspar abundance increases from north to south across the width of unit 2.

This chemically-identified variation in mineral abundance across traverse 7 is also weakly expressed in both the field measurements and thin section estimates of the mode (Fig. 2.2; Table A2.1).

Some compositional variation can also be attributed to changes in mineral composition. The average Fo* (molar $100 \cdot \text{Mg}/[\text{Mg} + \text{Fe}]$) of olivine, as an example, increases from Fo₁₈ to Fo₂₄ towards the north side of unit 2, and normative feldspar compositions are less calcic, and more sodic and potassic towards the south side of unit 2.

Rocks of unit 1b are found on both sides of unit 2. Comparison of the chemistry of samples of unit 1b, 4 from the north side and 2 from the south, gives some preliminary evidence for asymmetry. Unit 1b samples from the south side have higher concentrations of Ca and lower concentrations of Zn, Ti, Fe, Mg and Ni, than unit 1b rocks from the north side (Fig. 6.2). This pattern is consistent with a greater abundance of mafic minerals (olivine, augite, and ilmenite) in unit 1b rocks on the north side. However, such a mineralogical variation is not obvious in the field measurements of mineral mode (Fig. 2.2) nor from thin section modal analyses (Table. A2.1)

6.2.2 Interpretation of Compositional Asymmetry

Feldspar which is more abundant towards the south side of unit 2 (and perhaps unit 1b) has lower density than the mafic minerals, such as the iron-titanium oxides, which are more abundant towards the

north side (Fig. 6.3). Such a distribution can be explained by density-controlled segregation of crystals in a melt within a non-vertical dyke-conduit. Less dense phases were accumulating to a greater extent on the hanging wall (south) side, while more dense phases were being concentrated on the foot wall (north) side. The dyke presently dips at 70° - 80° S (Table 2.2.4) and the compositional data in Fig. 6.2 suggests that this dip was primary, i.e. was present during the emplacement and crystallization of the dyke. Compositional asymmetry across non-vertical dykes of other swarms (e.g. Platten and Watterson, 1987) has also been attributed to crystal settling in a non-vertical magma conduit (Komar, 1972).

Several other asymmetric features are noted at traverse 7. The unit 1b zone is narrower, the compositional gradient between units 1b and 2 is sharper and the synformal foliation of unit 2 has a steeper limb on the south side of the dyke than on the north side (Fig. 2.2.3 and 2.2.4). The origin of these additional asymmetries remains unknown.

6.2.3 Across-Dyke Variation in Unit 1 Rocks

Compositional profiles across unit 1, particularly at traverse 15, show an overall increase in incompatible element concentration from margin to interior (Fig. 6.1). In addition, the Mg:Fe ratios of olivine and augite tend to decrease from the dyke margin inwards (Table A3.1). These whole-rock and mineral compositions suggest that the unit 1 magma became more highly fractionated towards the dyke

interior. This is consistent with a model of mineral growth on the inward-growing liquid-solid interface of the dyke, with the result that the liquid in the interior becomes progressively more evolved (Irving, 1980; Platten and Watterson, 1987).

The whole-rock data from most traverses show irregular unit 1 profiles. The abrupt 'jumps' in chemistry suggest that the magma was heterogeneous and was probably emplaced in pulses. Field evidence for multiple pulses (i.e. between units 1a and 1b) was described at traverse 7 (Section 2.2.2).

6.2.4 Cumulus Zones in Unit 1 Rocks

Pearce ratios have the form A/Z where A and Z are compositional variables, and Z has the additional property of behaving as an incompatible element (Appendix 6). Pearce ratios can be used to provide a purely chemical definition of cumulates and non-cumulates. A sample containing cumulus mineral 'A', has, by definition, a larger Pearce ratio (A/Z) than the corresponding Pearce ratio of any parental magma. Non-cumulates are those with smaller Pearce ratios than the parental magma.

Using this chemical definition for cumulates, it appears that samples from unit 1 near the contact with unit 2 contain cumulus augite (Fig. 6.1C; CIPW diopside), apatite (Fig. 6.1F), titanomagnetite (Fig. 6.1D; CIPW magnetite), and ilmenite (Fig. 6.1E). These same samples appear to lack cumulus plagioclase and olivine (Figs. 6.1A and B). However, cumulus plagioclase and olivine are present in samples along the boundary between units 1a and 1b at

traverse 7, and possibly from samples near the south side of traverses 1, 4, 5, 7 and 14 and on the north margin of traverse 2 (see Section 7.3 and Fig. 6.1A and 6.1B).

6.2.5 Along-Dyke Trends in Unit 1 Data

The incompatible element concentrations in unit 1 samples (within 30 m of the margin) are displayed in Fig. 6.4. These data (excluding the data from satellite dykelets) exhibit a weak increase in incompatible element abundance towards the northeast along the dyke. Many of the samples between 10 and 30 m away from the margin are probably cumulates (Section 6.2.4) and are therefore not representative of liquid compositions. The remaining samples from within 10 m of the margin, mostly non-cumulates, still exhibit an increase in incompatible element content towards the northeast (Fig 6.4).

The longitudinal trend in unit 1 chemistry can be interpreted with the aid of maps in Fig. 6.1 which show the regional variation in Pearce ratio abundances of various normative minerals. There is a weak tendency for plagioclase and olivine abundances in unit 1 rocks to decrease towards the northeast end of the dyke. However, no along-trend is discernible in the Pearce ratio abundances of augite (CIPW diopside), alkali feldspar (CIPW orthoclase), titanomagnetite (CIPW magnetite) or ilmenite.

The along-dyke increase in incompatible element abundance and the decrease in absolute plagioclase and olivine abundances (based on the

Pearce ratios) towards the northeast can be interpreted in terms of a northeasterly moving magma evolving en-route by side-wall fractionation (e.g. Irving, 1980).

The chemistry of minerals in unit 1 varies erratically along the dyke (Fig. 6.5). The Ti content in titanomagnetite (Fig. 6.5D) and ilmenite (Fig. 6.5E) from unit 1 rocks shows a weak increase towards the northeast, but olivine, augite and feldspar (Figs. 6.5A-C) lack any pattern of along-dyke compositional variation. Any along-dyke trend in olivine, augite and feldspar is obscured by the large spread in values from each sample, a consequence of the heterogeneity in mineral chemistry on a thin section-scale (Section 4.2.6).

6.2.6 Satellite Dykelets

The satellite dykelets show no along-dyke trend in incompatible element content (Fig. 6.4) unlike the near margin samples which tend to increase in incompatible element content towards the northeast (Section 6.2.5). Both satellite dykelet and near margin samples represent liquid compositions. The absence of an along-dyke trend for the satellite dykelets may be explained by hypothesizing that while some satellite dykelets are fed by near margin magma, that other dykelets, indistinguishable from the former, are fed from the dyke interior. Any along-dyke pattern in satellite dykelets derived from the near margin magma would be obscured by the satellite dykelets derived from more-evolved interior magma.

6.3 ALONG-DYKE TRENDS IN UNIT 2 DATA

The composition of unit 2 varies systematically along the dyke (Fig. 3.2). For example, the $\text{FeO}/\text{Al}_2\text{O}_3$ ratio shows a progressive increase towards the northeast (Fig. 3.2B). Longitudinal variation by other elements is displayed in Fig. 6.6 and by modal plagioclase in Figs 6.7A, 6.7B. There may also be a weak longitudinal (along-dyke) gradient in the chemistry of minerals from unit 2 (Fig. 6.5). Olivines have lower Mg/Fe ratios, i.e. more evolved compositions, towards the northeast, but no systematic variation is observed in feldspar, augite, titanomagnetite or ilmenite compositions.

The whole-rock trends can be interpreted with the aid of the normalized Pearce ratio maps (Fig. 6.1). The longitudinal trend in unit 2 data is caused by an increase in the Pearce ratio abundances of olivine, augite, apatite, titanomagnetite and ilmenite and a decrease in the Pearce ratio abundance of plagioclase from northeast to southwest along the dyke.

The observed compositional pattern may correspond to a genuine horizontal gradient in mineral abundances (Fig. 6.8A), or to an oblique section through the dyke so that a vertical zonation is expressed as a longitudinal gradient (Fig. 6.8B). Because only one section through the dyke is exposed, it is difficult to choose between these two models.

6.4 MASS-BALANCE IN THE DYKE

It is possible to use the Pearce ratio maps of Fig. 6.1 to make rough mass-balance calculations of the 'mineral budget' for the GAD as

a whole. In other words, it is possible to estimate for each mineral type whether fractional loss in some part of the GAD is balanced by concentration as cumulates in other parts of the GAD. Of course, this can be done only for the present level of exposure of the GAD. The 'mineral budget' for sections above or below the present exposure level can not be directly determined. Nevertheless, this exercise yields some important insights regarding the crystallization history of the dyke.

The Pearce ratio maps for each mineral type are considered. For each map, those portions of the dyke which have experienced fractionation are compared with those portions that consist of cumulates. Whether a sample was derived by fractionation or as a cumulate from the parental magma can be determined by comparing Pearce ratio circle-size of that sample with the circle-size of the reference sample (RE8401.46) representing the composition of the parental magma. A sample representing a magma derived by fractional removal of minerals will have a smaller circle-size than the reference sample. A sample representing a magma derived by accumulation of minerals (i.e. a cumulate) will have a larger circle size.

In unit 1 rocks, plagioclase and olivine show enrichment (i.e. cumulate behaviour) over small scattered regions of unit 1. Cumulus augite, titanomagnetite, ilmenite and apatite are present only in a narrow region of unit 1 near unit 2. Overall, there is a qualitative balance in unit 1 rocks between mineral losses (through fractionation) and gains (as cumulates). This implies that the unit 1 magma could

have crystallized entirely as a closed system.

The relationship between units 1 and 2 is dramatically different. It has been shown (Chapters 2 and 3) that unit 1 and 2 rocks are co-genetic and both could be derived by fractional crystallization from the same parental magma. As seen on the Pearce ratio maps (Fig. 6.1; see also Section 5.4), derivation of unit 2 from the parental magma requires substantial loss of plagioclase, olivine, and minor loss of titanomagnetite and ilmenite. At the same time, augite, alkali feldspar and apatite have not been lost.

The minerals which have been lost during derivation of unit 2 liquid from the parental magma are not present as cumulates anywhere along the present exposure level of the dyke. The possibility that these minerals were carried to deeper exposure levels can not be ruled out. On the other hand, it is also possible that unit 2 was derived in an external chamber, in which case the fractionate could remain behind in that chamber.

6.5 CONCLUSIONS

The principal conclusions of this chapter are:

- (1) The composition of unit 2 and possibly 1b rocks at traverse #7 vary asymmetrically across the dyke. This variation can be attributed to magma crystallization in a non-vertical dyke conduit.
- (2) The unit 1 magma became more evolved towards the dyke interior.
- (3) Unit 1 rocks from near the boundary with unit 2 consist of augite, apatite, titanomagnetite and ilmenite cumulates.

- (4) Near-margin samples of unit 1 become slightly more enriched in the incompatible-elements towards the northeast end of the dyke.
- (5) Unit 2 rocks become more plagioclase-rich and olivine- and augite-poor towards the northeast end of unit 2.
- (6) Mass balance considerations suggest that derivation of unit 2 magma from a parental unit 1 magma requires substantial olivine and plagioclase loss.

Fig. 6.1: Normalized Pearce ratio maps showing the regional variation of variables of the form, $[A/Z] \cdot Z_0$. CIPW normative abundances are used for A. The variable, Z, is given by the abundance of Ba. Z_0 is given by, Ba_0 , the Ba content in RE8401.46 (Section 3.6). An arrow locates this sample. Note that while the magnitude of the data is given by the varying circle size, the range in circle size is the same for all maps. For instance, the range in alkali feldspar abundance (B) is much smaller than the range in plagioclase abundance (A), yet the range in circle size is the same for both plots. The areal extent of unit 2 rocks is indicated by a ruled pattern.

Fig. 6.1

A

Fig. 6.1

(Continued on next page)

Fig. 6.1

DIOPSIDE $\times \left(\frac{Ba_0}{Ba} \right)$

14.02 $\bigcirc$
 5.83 $\ominus$
 0.88 $\bullet$

(Continued on next page)

Fig. 6.1

(Continued on next page)

Fig. 6.1 ¹⁶²E

ILMENITE $\times (\frac{BaO}{Ba})$

9.51
 4.15
 0.76

(Continued on next page)

Fig. 6.1

F

(Continued on next page)

ORTHOCLASE $\times (\frac{Ba_0}{Ba})$

Fig. 6.1 164 **G**

Fig. 6.2: Chemical profiles across dyke at traverse 7. Subdivisions of dyke are taken from Figs. 2.2 and 2.3. The data from the north half of the traverse were also 'mirrored-imaged' about the mid-line of the dyke and superimposed on the data from the south half as a dotted line. This was done in order to assess the bilateral compositional symmetry of the dyke. Oxide abundances are all in wt%. Remaining elemental abundances are in ppm. The Fo content of olivines is computed from $100 \cdot \text{Mg}/(\text{Mg} + \text{Fe})$ and is tabulated in Table 4.1. The length of each error bar equals the 2s analytical uncertainty. Profiles with no error bar have 2s uncertainty no larger than approximately twice the size of the plot symbols.

Fig. 6.2

TRAVERSE 7

(Continued on next page)

Fig. 6.2

TRAVERSE 7

Fig. 6.3: Interpretation of field and chemical data from traverse 7. Subdivisions of dyke are from Figs. 2.2 and 2.3. Dyke margin is located by solid line which becomes a heavy dashed line above the present exposure level. Thin dashed line above present exposure level locates contact between unit 1 and unit 2. Parabolas denote postulated foliation surfaces. The data illustrates accumulation of elements hosted in feldspar towards the hanging wall side and the components of mafic minerals towards the foot wall side of the dyke.

Fig. 6.4: Along-dyke variation in the incompatible element chemistry of unit 1 samples. The length of the error bar equals the 2s analytical uncertainty. Two data points (marked by arrows) on the Ba graph are from satellite dykelets which were probably affected by in-situ contamination (Section 3.2).

(Continued on next page)

Fig. 6.4

(Continued on next page)

3

Fig. 6.4

(Continued on next page)

Fig. 6.4

(Continued on next page)

Fig. 6.4

(Continued on next page)

Fig. 6.4

Fig. 6.5: Along-dyke variation in mineral chemistry. Each symbol represents a separate analysis and multiple analyses from the same sample are plotted along the same vertical line. Data from different samples, each from the same traverse, are grouped by the brackets. For ilmenite the length of the error bar equals the 2s analytical uncertainty. For the other minerals, the 2s analytical uncertainty is no larger than the plot symbol size. Fo* and En* are molar $100 \cdot \text{Mg}/(\text{Mg} + \text{Fe})$ for olivine and augite, respectively. An* is molar $100 \cdot \text{Ca}/(\text{Ca} + \text{Na} + \text{K})$. Usp* and Ilm* are defined in Appendix A3.1. Data is from Table A3.1. The graphs are presented in the order: olivine, augite, feldspar, ilmenite and titanomagnetite.

Fig. 6.5

Fig. 6.5

AUGITE

Fig. 6.5

FELDSPAR

178

(Continued on next page)

Fig. 6.5

ILMENITE

Fig. 6.6: Longitudinal compositional variation in unit 2. The regression line and $2s$ error about the line are shown. R is correlation coefficient. Figure taken from Ernst et al. (1987). For each of these graphs the slope is significantly different from zero at the 95% confidence level. For graph A, the slope is positive and for graphs B, C and D the slope is negative. The test statistic is t with $n-2$ degrees of freedom, where $n=40$ (Johnson, 1973, pp. 357-359). $t = 8.89, 6.28, 7.44$ and 5.54 for graphs A, B, C and D, respectively.

Fig. 6.7: Bivariate (X-Y) plots of whole-rock data and proposed differentiation trend. A and B are coded by Ba content. The 2s analytical uncertainty in each graph is no larger than the size of the plot symbols. Underlined numbers plotted alongside selected data points give percentages of felsic minerals (mostly plagioclase). C and D show generalized distributions of data from units 1 and 2. Arrow indicates fractionation trend. Note the correlation between the chemistry of unit 2 data (Ba > 1300 ppm) and the percentage of felsic material (mostly plagioclase). Figure from Ernst et al. (1987).

Fig. 6.8: Schematic interpretations of the longitudinal compositional variation in unit 2 data. Open circles indicate plagioclase abundance. Filled circles indicate mafic silicates, olivine, augite, titanomagnetite and ilmenite. Note that throughout the 'dyke' the relative abundances of mafic minerals and feldspar change, but that their total abundance relative to interstitial liquid (spaces between circles) remains constant. (A) horizontally-zoned dyke and (B) oblique slice through a vertically-zoned dyke.

CHAPTER 7

ORIGIN OF THE PARENTAL MAGMA

7.1 INTRODUCTION

Previous chapters have shown that the rocks of the Great Abitibi Dyke (GAD) were derived by fractional crystallization of a parental magma similar in composition to the chilled margin samples. The current chapter covers the origin of the parental magma, both its mantle origin and its history of differentiation prior to emplacement in the dyke. This information is obtained primarily using incompatible element chemistry.

7.2 RARE EARTH ELEMENTS

7.2.1 Rare Earth Element Slopes

The REEs in rocks of the GAD exhibit a distinct positive Eu anomaly superimposed on an otherwise smooth, straight, and consistently light REE-enriched pattern (Figs. 7.1 and 7.2). The REE patterns are sub-parallel and have a chondrite normalized (cn) slope, $(La/Yb)_{cn}$, of 8.5 ± 1.0 . The data vary in abundance over a factor of three; La_{cn} ranges between 40 and 120 and Yb_{cn} between 5 and 15. The sub-parallel character of the REE patterns is consistent with the model of fractionation dominated by plagioclase and olivine (Chapter 5). Fractionation of either of these minerals does not affect the REE slope of the residual liquid (McBirney, 1984, p. 175).

The Mg# (molar $100 \cdot Mg/(Mg+Fe)$), and Mg, Ni and Cr contents of the parental magma (Table 3.6) are too low for the magma to be in

equilibrium with mantle olivines (e.g. BVSP, 1981, pp. 409-432; McBirney, 1984, pp. 284-285). Therefore, the parental magma does not represent a primary mantle melt. The primary mantle melt must have undergone substantial fractionation, probably of olivine, prior to emplacement in the GAD. However, since fractionation of olivine does not change the slope of REE patterns (Cox et al., 1979, p. 334), the primary mantle melt will probably have the same light REE-enriched slope as the GAD data. However, if assimilation accompanied crystallization (DePaolo, 1981) then the REE pattern would probably not match that of the primary mantle melt. The effect of assimilation-fractional crystallization on the primary magma has yet to be investigated.

In the absence assimilation-fractional crystallization (DePaolo, 1981) the light REE-enriched patterns, characteristic of the GAD and the primary mantle magma, are consistent with low degrees (a few percent) of partial melting of a garnet lherzolite mantle in which garnet is left as a residual phase (e.g. Cox et al., 1979, pp. 336-339). The light REE-enriched patterns could also be due to partial melting of a mantle source which had been metasomatically enriched in the light REEs (e.g. Nielson and Noller, 1987).

7.2.2 Europium Anomaly

Europium Anomaly in Chilled Margin and Satellite Dykelet Samples

The REE data from the GAD, including those from chilled margins and satellite dykelets, suggest a slight positive europium (Eu) anomaly i.e. $Eu/Eu^* > 1$ where Eu^* is the value interpolated between

nearby trivalent REEs (Sm and Tb) and Eu is the actual measured value (Tables 3.6 and A5.1). Chilled margin and satellite dykelet samples of the GAD characteristically contain small phenocrysts of lath-shaped plagioclase (Section 2.2.4). Since plagioclase preferentially concentrates Eu (e.g. BVSP, 1981, pp. 321-322), accumulation of plagioclase phenocrysts could potentially explain the Eu anomaly in chilled margin and satellite dykelet samples.

However, both textural evidence and mathematical modelling indicate that plagioclase accumulation is not responsible for the Eu anomaly. Sample RE8204.16B, from a dykelet that cuts unit 1 rocks at traverse 4, contains plagioclase phenocrysts which increase in size and abundance inwards from the margin of the dykelet. These phenocrysts clearly grew in-situ and any positive Eu anomaly for sample RE8204.16B must be primary.

The origin of the Eu anomaly can also be assessed by calculating the abundance of plagioclase phenocrysts that must be added to each chilled margin or satellite dykelet sample in order to produce the observed positive Eu anomaly. The calculated abundance is then compared with the observed abundance of plagioclase phenocrysts. If the calculated excess of plagioclase is larger than the observed phenocryst abundance, then the observed Eu anomaly is at least partially characteristic of the magma and is not a consequence of in-situ plagioclase accumulation.

This calculation requires a value for the K_D of Eu (between plagioclase and melt), a parameter which varies with the oxygen

fugacity of the melt. Values for the K_D of Eu generally range between 0.3 to 2.1 (Cox et al., 1979, p. 334; Drake and Weill, 1975). Another value needed for modelling is the K_D of Eu^* (between plagioclase and melt). Values for the K_D of Eu^* range from 0.1 to 0.6 for basaltic and andesitic melts, respectively (Cox et al., 1979, p. 334).

Modelling in Table 7.1 uses a range of values for $K_D(\text{Eu}^*)$ and $K_D(\text{Eu})$ which are designed to provide a stringent test of the accumulation hypothesis. Use of $K_D(\text{Eu}) < 1$ (e.g. 0.3) or $K_D(\text{Eu}^*) > 0.1$ (e.g. 2.1) would result in still larger values for calculated plagioclase enrichment. The calculations in Table 7.1 show that at least 13% and perhaps 46% plagioclase enrichment is implied by the size of the Eu anomaly, an amount significantly larger than the observed abundance of plagioclase phenocrysts, typically about 5%. It can therefore be concluded that the positive Eu anomaly in the chilled margin and satellite dykelet samples could not entirely be due to phenocryst accumulation, and must be characteristic of the parental magma.

Variation in the Europium Anomaly Within the GAD

The size of the Eu anomaly decreases with increasing evolution of the parental magma as monitored by the La content (Fig. 7.3). A few samples with much larger Eu anomalies (1.7 to 2.3) and low La_N values (bottom right side of Fig. 7.3) are plagioclase cumulates. These are sample RE8204.14, from traverse 4, and samples RE8203.13, RE8203.14 and RE8203.15, from traverse 5.

7.3 TECTONIC SETTING: WITHIN PLATE BASALT

The tectonic setting of the GAD can be identified through major and trace element diagrams (Fig. 7.4, 7.5 and 7.6). All these diagrams can differentiate between oceanic within-plate basalts (WPBs), island arc basalts (IABs) and ocean-floor basalts (OFBs) (also called mid-ocean ridge basalts, MORBs). Some continental flood basalts (CFBs) also plot in the WPB field (Duncan, 1987; Marsh, 1987). The diagrams are specifically designed for non-cumulate rocks and thus data from cumulate portions of the GAD cannot be interpreted using these diagrams.

Three diagrams are used: the F1-F2 diagram (Pearce, 1976), the log Zr vs log Zr/Y diagram (Pearce and Norry, 1979) and the ternary Ti-Zr-Y diagram (Pearce and Cann, 1973). On all three diagrams the data from unit 1 and 2 rocks plot into separate groups and most data plot within the WPB field (Figs. 7.4, 7.5 and 7.6). These data points on the F1-F2 and the log(Zr) vs log(Zr/Y) diagrams which plot outside of all fields are cumulates (Section 6.2.4). On the Ti-Zr-Y plot (Pearce and Cann, 1973), approximately half of the data has anomalously high Ti contents and plots outside of all four compositional fields (Fig. 7.6). These are unit 1 samples. Those with the highest Ti values are cumulates. The remainder are non-cumulates and their high Ti contents are attributed to an anomalously Ti-rich parental magma.

7.4 SPIDERGRAMS

7.4.1 Introduction

Elements which partition strongly into the liquid during partial melting of lherzolitic mantle can be normalized and plotted (Fig. 7.7) as a 'spidergram' on a 'spider diagram' (Thompson, et al., 1984). All elements are chondrite-normalized except for K, Rb and P which are normalized to 'primitive' mantle abundances. Element order (from right to left) on the diagram reflects increasing elemental incompatibility during low degrees of partial melting of mantle lherzolite (Thompson, et al., 1984).

Spidergrams are useful in assessing the characteristics of the mantle source area and the subsequent petrogenetic history of magma. The mean values and the 1 standard deviation variations for unit 1 and unit 2 samples are presented in Fig. 7.7. The unit 1 and 2 data have essentially parallel patterns in all elements except Sr, Ti, and Eu.

The data as a whole can be more easily interpreted after it has been normalized a second time (Fig. 7.8). This second normalization shifts spidergrams 'up' or 'down' so that the Y content of each sample is equal to 15. Normalization to constant Y has the effect of eliminating the scatter caused by fractional crystallization of the principal minerals crystallized by the GAD, olivine, and plagioclase (Thompson et al, 1982; Thompson et al., 1983 and Chapter 5).

7.4.2 General Shape of Spidergrams

Spidergrams from the GAD are compared with reference spidergrams in order to determine magma type. Four reference patterns are shown in

Fig. 7.9. These are: mid-ocean ridge basalt (MORB), ocean island basalt (OIB), crustally contaminated continental flood basalt (CFB) and island arc basalt (IAB). OIB spidergrams (e.g. BVHO-1) as well as crustally uncontaminated CFB spidergrams (not shown) have a similar concave downward pattern (Thompson et al., 1984) and are both types of within plate basalt (WPB). Thompson et al. (1983) suggests that OIBs and CFBs originate from the same mantle reservoir and that if crustal contamination occurs, then CFBs acquire a different pattern. Crustally contaminated CFBs such as BCR-1 typically exhibit an overall linear spidergram which is enriched in Ba, Rb, Th, K, and the light REEs but is unchanged or slightly depleted in Nb, Ta, P, Zr, Hf, Ti and Y relative to uncontaminated CFBs (Thompson et al., 1984). Island arc basalts (e.g. EPI-10) have a distinctive Nb-Ta trough (Thompson et al., 1984). MORB rocks are characterized by a pattern of decreasing abundance towards the left side of the spidergram.

The spidergrams from the GAD have a different pattern of elemental enrichment and depletion than do contaminated CRBs, and have very different overall shape than MORBs. The average spidergram from the GAD is most similar to that of WPBs (i.e. OIBs and uncontaminated CFBs), a conclusion that is similar to that drawn in Section 7.3 based on various trace-element discriminant diagrams. IABs are characterized by a Nb-Ta trough and the rocks of the GAD have a slight Nb trough but no Ta anomaly. Regarding this, the Nb/Ta ratio in rocks of the GAD is approximately 11 and yet in typical basalts the average value should be 17 (Condie, pers. comm, 1989). This suggests that either Nb values

may be too low or Ta values too high. Consideration of analyses on international standards (see Appendix A1) suggests that Nb values used in Figs. 7.7, 7.8 and 7.9 may be slightly underestimated. If so then the Nb values may be higher, in which case the Nb trough would be eliminated and the data would fit better to an OIB pattern.

7.4.3 Anomalies in the Spidergrams

The fit of the GAD spidergrams to an idealized OIB pattern (Fig. 7.9) is only approximate. GAD spidergrams are anomalous relative to an OIB pattern in certain elements. Both unit 1 and 2 spidergrams have positive Ba, K, P and Eu anomalies and negative Zr and Hf anomalies. Rb is highly variable in abundance. In addition, unit 1 spidergrams have positive Ti and slightly positive Sr anomalies. Unit 2 spidergrams have a negative Sr anomaly but no Ti anomaly.

The spread in Rb data is attributed to in-situ contamination of some chilled margin and satellite dykelet samples (Section 3.2). The positive Ti anomaly observed in unit 1 rocks and absent from unit 2 rocks requires an explanation. Genesis of the unit 2 magma involved titanomagnetite and ilmenite fractionation which 'erased' the Ti anomaly in the parental unit 1 magma. Unit 1 samples suggest a weak positive Sr anomaly relative to the adjacent elements, Ce and Nd (Fig. 7.7) which contrasts with the negative Sr anomaly in unit 2 rocks. The weak positive Sr anomaly is characteristic of the parental magma while the negative anomaly in unit 2 rocks is produced by extensive plagioclase fractionation. A positive Eu anomaly is characteristic of

the parental magma (Section 7.2.2; Fig. 7.3). The size of this Eu anomaly is slightly smaller in unit 2 than in unit 1 rocks. The decreased size of the Eu anomaly in unit 2 rocks is probably also a consequence of plagioclase fractionation (Fig. 7.3).

The positive Ba, K, P, Sr, Eu and Ti and negative Zr, Hf anomalies present in the near margin samples are considered characteristic of the parental magma. In other words, these features were acquired prior to emplacement of the GAD. Several origins are considered.

Most of these anomalies can be potentially linked to fractionation or accumulation of specific minerals, apatite for P, plagioclase for Eu, iron-titanium oxides for Ti and zircon and baddeleyite for Zr and Hf. Fractionation or accumulation of these minerals could have occurred in a magma chamber prior to emplacement. The Ba, K, Eu and Sr anomalies could also be produced through assimilation of granitoid rocks (Fig. 6 in Thompson et al., 1983), or combined assimilation-fractional crystallization (DePaolo, 1981). Any of the anomalies could also have been acquired directly during partial melting of suitably anomalous mantle.

Circumstantial evidence suggests a mantle origin for the Ba and K anomalies. Average spidergrams are given by Condie et al. (1987) for all the dyke swarms which cut the Abitibi belt. Only the Abitibi and Sudbury swarms with ages of 1140 and 1238 Ma, respectively (Krogh et al., 1987) show large Ba and K anomalies. The older Hearst-Matachewan and Preissac swarms with ages of 2454 and 2140 Ma respectively

(Heaman, 1988; Fahrig and West, 1986), lack these anomalies. If the Sudbury and Abitibi dykes traversed the same region of crust as the earlier Hearst-Matachewan and Preissac magmas, then a crustal origin for the Ba and K anomalies is unlikely. Condie et al (1987) proposed that the Sudbury and Abitibi swarms come from a different (deeper) source area than the earlier swarms. It is postulated that melting of this deeper source area produced a Ba- and K-rich primary GAD magma.

7.5 CONCLUSIONS

Several conclusions can be made regarding the genesis of the parental magma to the GAD:

- (1) Trace and major element discriminant diagrams as well as incompatible element spidergrams reveal that the magma-type of the GAD is a within-plate basalt (WPB).
- (2) The parental magma is anomalously enriched in Ba, K, P, Sr, Eu and Ti and depleted in Zr and Hf relative to a typical OIB pattern. These anomalies were acquired either from the mantle source area or as a consequence of differentiation within the crust prior to emplacement.

Fig. 7.1: Rare earth element data from 53 rocks of the GAD. Rare earth abundances are chondrite-normalized using the normalization factors of Taylor (1980). Data are grouped by site (e.g. site 82 04) and the number marked by each REE pattern is the sample number (e.g. 10. Sample number 8204.10 would have site no. 82 04 and sample no. 10.

(Continued on next page)

Fig. 7.1

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Fig. 7.1

(Continued on next page)

Fig. 7.1

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Fig. 7.1

Fig. 7.2: La/Yb vs La. 'cn' means chondrite normalized; normalization factors after Taylor (1980). Inset shows range of REE data. The cross indicates the average $\pm 2s$ analytical uncertainty for the data. Data from both unit 1 and 2 samples are plotted.

Fig. 7.3: La vs Eu anomaly (Eu/Eu^*). Eu^* is Eu value interpolated from values of adjacent trivalent REEs. Inset shows range of REE data. Unit 2 data are enclosed by a line. The cross indicates the average $\pm 2s$ analytical uncertainty for the data.

Table 7.1: Test for origin of Eu/Eu^* anomaly in chilled margin samples

Question: Can the Eu/Eu^* anomaly observed in chilled margin samples be explained by a cumulate model for the observed plagioclase phenocrysts.

Solution: Model the addition of plagioclase phenocrysts to a melt as a material-balance problem.

Let:

L equal the amount of the initial liquid (in grams, litres, or moles, etc.),

P equal the amount of the phenocrysts,

T equal the total amount of the liquid and phenocrysts (equals $L+P$),

Eu_L , Eu_P and Eu_T equal the concentration of Eu in the initial liquid, phenocrysts and total (liquid plus phenocrysts), respectively, and

Eu_L^* , Eu_P^* and Eu_T^* equal the concentration of Eu^* in the initial liquid, phenocrysts and total (liquid plus phenocrysts), respectively.

Derive material-balance equations for Eu and Eu^* and divide the two equations by each other:

$$\frac{L \cdot \text{Eu}_L + P \cdot \text{Eu}_P}{L \cdot \text{Eu}_L^* + P \cdot \text{Eu}_P^*} = \frac{T \cdot \text{Eu}_T}{T \cdot \text{Eu}_T^*} = \frac{\text{Eu}_T}{\text{Eu}_T^*} \quad (1)$$

Consider that the initial melt has no Eu anomaly:

$$\text{Eu}_L = \text{Eu}_L^* \quad (2)$$

Substitution of eqn. 2 into 1, rearranging and remembering that $T=L+P$ yields:

$$\frac{1 - \text{Eu}_T/\text{Eu}_T^*}{\text{Eu}_T/\text{Eu}_T^* + \text{Eu}_P^*/\text{Eu}_L^* - \text{Eu}_P/\text{Eu}_L + 1 - \text{Eu}_T/\text{Eu}_T^*} = \frac{P}{T} \quad (3)$$

where:

$$\text{Eu}_T/\text{Eu}_T^* = \text{Eu anomaly}$$

$$\text{Eu}_P^*/\text{Eu}_L^* = K_D (\text{Eu}^* \text{ in plagioclase})$$

$$\text{Eu}_P/\text{Eu}_L = K_D (\text{Eu in plagioclase})$$

P/T = calculated concentration of plagioclase phenocrysts

Sample No.	Traverse No.	Analyzed Eu/Eu^*	Plagioclase Phenocrysts (Calculated)			Plagioclase Phenocrysts (Point-Counted) ¹
			$K_D(\text{Eu})=1$ $K_D(\text{Eu}^*)=0$	$K_D(\text{Eu})=2$ $K_D(\text{Eu}^*)=0$	$K_D(\text{Eu})=1$ $K_D(\text{Eu}^*)=0.1$	
8204.07	4	1.40	29%(wt.%)	16%	32%	5.4% (vol.%) ²
8204.19	4	1.38	28%	16%	31%	4.8%
8207.03	14	1.71	42%	26%	46%	5.3%
8207.05	14	1.30	23%	13%	26%	7.3%
8207.13	14	1.47	32%	19%	36%	5.8%
8208.09	15	1.31	24%	13%	26%	3.3%

¹Point-counted on slab surfaces of samples. For each, a minimum of 1000 points were counted over an area of at least 12.5 square centimeters.

²Conversion between volume % and weight % will not change conclusion that calculated phenocryst content is much larger than observed phenocryst content.

Fig. 7.4: F1-F2 diagram (Pearce, 1976) for distinguishing basalt types. F1 and F2 are derived from linear combinations of major element contents (as wt% oxides). WPB = within-plate basalts, OFB = ocean-floor basalts, LKT = low-potassium tholeiites, CAB is calc-alkali basalts, and SHO is shoshonites. Data symbols are the same as in Fig. 3.6. The cross indicates the average $\pm 2s$ analytical uncertainty for the data.

Fig. 7.5: Zr/Y vs Zr diagram (Pearce and Norry, 1979) used to identify the tectonic setting. WPB = within-plate-basalt, MORB = mid-ocean-ridge-basalt, and IAB = island-arc-basalt. Note rhomb-shaped area in which the fields of WPB and MORB overlap. Data symbols are the same as in Figure 3.12. The cross indicates the $\pm 2s$ analytical uncertainty for the data.

Fig. 7.6: Ti-Zr-Y ternary diagram (Pearce and Cann, 1973) used to identify the tectonic setting. IAB = island arc basalt, OFB = ocean floor basalt, CAB = calc-alkali basalt, and WPB = within-plate basalt. The data symbols are the same as in Figure 3.6. Error polygon indicates the average $\pm 2s$ analytical uncertainty.

Fig. 7.7: Spidergrams of data from the GAD. Element order and normalizing factors after Thompson et al. (1983). Normalizing factor for Eu after McBirney (1985). For each element, the mean and 1 σ envelope (patterned) are plotted. Average values for unit 1 and unit 2 data are located by square and circle symbols, respectively. Data from unit 1 and unit 2 are averaged separately. The values for Ba, Rb, K, Sr, P, Zr, Ti, and Y are each based on 158 analyses (118 for unit 1 samples and 40 for unit 2 samples). The Nb value is based on 125 samples (88 for unit 1 samples and 37 for unit 2 samples). Values for each of the remaining elements are based on 50 analyses (45 for unit 1 samples and 5 for unit 2 samples).

Fig. 7.8: Doubly-normalized spidergrams of GAD data. Data for each element are first divided by the appropriate 'mantle' normalization factor (Thompson et al., 1983). Data are further normalized by the ratio $15/Y$. This has the effect that all patterns are shifted slightly up or down so that the normalized Y value for each sample equals 15. The mean, 1 σ and 2 σ envelopes, and maximum and minimum values are calculated from the doubly normalized spidergrams (for all unit 1 and 2 data combined).

Fig. 7.9: Comparison of doubly-normalized GAD spidergrams (from Fig. 7.8) with those from various settings (Thompson et al., 1983). The data from the GAD and its 1 σ range are located by the vertical ruled pattern. BCR-1 is a sample from the Columbia River Plateau basalts and represents crustally contaminated continental flood basalts (CFB). BHVO-1 is basalt from Kilauea, Hawaii and represents a typical ocean island basalt (OIB) pattern, and MORB is a typical mid-ocean ridge basalt. EPI-10 is a typical island arc basalt (IAB) from the New Hebrides (Thompson et al., 1984). BCR-1 and BHVO-1 are also international analytical standards. A smooth line (bold and unlabelled) is fitted to the GAD data and has the concave downward shape typical of OIB patterns (Thompson et al., 1984).

CHAPTER 8

ANISOTROPY OF MAGNETIC SUSCEPTIBILITY

8.1 INTRODUCTION

Anisotropy of magnetic susceptibility (AMS) measurements were made on a representative suite of samples in order to define and interpret the magnetic fabric of the Great Abitibi Dyke (GAD). Magnetic fabric can potentially be used as an indicator of magma flow direction.

The low-field magnetic susceptibility, $\underline{K}$, is a symmetrical second rank tensor which relates a weak-field applied magnetic vector, $\underline{H}$, to the magnetization, $\underline{M}$, induced in a material (Nye, 1969; Payne, 1981).

$$\underline{M} = \underline{K} \underline{H} \quad (8.1)$$

Magnetic susceptibility, $\underline{K}$, can be geometrically represented by an ellipsoid whose long, intermediate and short axes define the orientations and magnitudes of the maximum, intermediate and minimum susceptibilities (Nye, 1969; Ellwood, 1978; Payne, 1981).

8.2 METHODS

8.2.1 Measurement Technique

Two hundred and eighty one specimens from 112 samples were analyzed using the Kappabridge susceptibility bridge, KLY-1, in order to determine, for each, the magnetic susceptibility tensor. The analytical procedure is detailed in Appendix 8 and results are listed

in Appendices 9 and 10.

The susceptibility data (both directions and magnitudes) from specimens were averaged to determine sample means, and sample means were averaged to determine site (or group) means. Data were averaged using the axis-averaging procedure described below.

8.2.2 Axis-Averaging of Data

In this method, each of the principal axes, K_1 , K_2 , K_3 (maximum, intermediate, and minimum) of the AMS ellipsoid is considered separately. The mean orientation of each axis for a set of samples is obtained using a matrix technique in which each axis is assumed to have unit length and is considered to have a distribution about the true mean of the sample population (termed the expected value, Edwards, 1964) given by the Watson-Scheidegger probability distribution (Scheidegger, 1965; Mark, 1973; Fisher, et al. 1987). For small angular deviations, the Watson-Scheidegger probability distribution has an approximately normal distribution.

8.3 FABRIC TYPE

8.3.1 Data From the GAD

There are two aspects of the magnetic fabric data which are relevant. These are (1) the type of the fabric (foliated or lineated); and (2) the orientation of the principal AMS axes. Fabric-type is considered in this section and the orientation of the fabric is considered in Sections 8.4 and 8.5.

An F-L diagram (Ellwood et al., 1988) is akin to the Flinn diagram used in structural geology. F and L indicate the degree of foliation and lineation, respectively. When F (or L) equals 1 then no foliation (or lineation) is present. An F-L diagram from the GAD (Fig. 8.1) reveals that both the degree of foliation and degree of lineation are weak (both F and L values are concentrated between 1.01 and 1.02). Overall, the data indicate more foliation than lineation.

The AMS data can also be characterized using a P-T diagram (Fig. 8.2) where P represents the degree of anisotropy (Nagata, 1961; Ellwood, et al., 1988) and T gives the shape (lineated or foliated) (Jelinek, 1981; Ellwood et al., 1988). Most specimens from the GAD have a degree of anisotropy between 1.02 and 1.04 which corresponds to a percentage anisotropy ($=100 \cdot (P-1)$) of 2% to 4%. Foliation predominates slightly over lineation ($T > 0$). A rough correlation between P and T (Fig. 8.2) suggests that as the rock becomes more magnetically anisotropic, its fabric changes from lineated ($T < 0$) to foliated ($T > 0$).

The degree of magnetic anisotropy observed in rocks of the GAD is similar to that observed for unmetamorphosed volcanic and plutonic rocks (Ellwood, 1977; Hrouda, 1982; Ellwood, 1984; Knight and Walker, 1988). The large scatter and the slight predominance of foliation over lineation observed in the data from the GAD are also evident in Hrouda's data.

8.3.2 Relationship Between AMS and Rock Fabric

The most important sources of low-field AMS in rocks containing titanomagnetite (and magnetite) are shape anisotropy, resulting from grain shape, and textural anisotropy, resulting from the stringing together of groups of grains (Khan, 1962; Smith and Prevot, 1977; Hrouda, 1982; MacDonald and Ellwood, 1987; Knight and Walker, 1988). Domain anisotropy (resulting from the alignment of magnetic domains in large multidomain grains) is stress-induced and may be removed by alternating field or thermal demagnetization techniques such as are used in palcomagnetic studies (Stacey, 1960; McEachern, 1988; Park et al., 1988).

Petrographic and microprobe investigation reveals that titanomagnetite is the dominant magnetic mineral in rocks of the GAD. Titanomagnetite typically composes about 5% of the rock and generally has grain size comparable to the associated silicate minerals. The shape and orientation of these titanomagnetite grains (or groups of grains) is probably responsible for the shape and orientation of the AMS fabric. Since 40% to 70% of the rock is composed of plagioclase (Chapter 2) any fabric expressed by plagioclase should also be reflected in the distribution of titanomagnetite grains. Unit 2 rocks exhibit a weak foliation defined by aligned feldspar laths and the orientation of this fabric is approximated by the AMS data (Section 8.4.5).

The orientations of the principal axes of titanomagnetite and feldspar fabrics should match regardless of the time of

titanomagnetite crystallization. If the titanomagnetite crystallizes early as in unit 2 rocks (Section 2.3.4), then later crystallizing plagioclase will grow around it, deform with it during flow, and adopt a similar final orientation. If, however, the titanomagnetite is a subliquidus phase as in unit 1 rocks (Section 2.3.4), it will crystallize in the intergranular spaces between the earlier formed plagioclase. In this case, the distribution of the titanomagnetite will mimic that of the feldspar (Hrouda, 1982, p. 58). This simple interpretation may be complicated by the presence of oxidation exsolution in titanomagnetites (Section 2.3.4).

Although the distribution of titanomagnetite (mimicked by plagioclase) is probably the source of magnetic anisotropy, the exact relationship between the magnitude of the AMS and rock fabrics has not been determined. Nor can it be predicted theoretically since the relationship between AMS and rock fabrics varies with both rock type and strain history (Borradaile, 1988; cf. Rathore, 1988). Furthermore, it remains to be explained how both unit 1 and 2 rocks can have a similar degree of magnetic anisotropy despite a marked difference in their degree of mineral foliation; unit 2 rocks are visibly foliated while unit 1 rocks are unfoliated.

8.4 CONTROLS ON AMS FABRIC

8.4.1 Introduction

Before presenting the orientation data from the GAD, rheological controls on the orientation of AMS fabric are considered. The

orientation of principal AMS axes typically parallels the rock fabric (Khan, 1962; Hrouda, 1982), and, therefore, the AMS data is considered a reliable guide to the orientation (but not the magnitude; e.g. Borradaile, 1988) of the rock fabric of the GAD. Several mechanisms which can result in development of a fabric in igneous rocks are considered below.

8.4.2 Effect of Rapid Crystallization at the Dyke Margin

Crystals can grow with long axes perpendicular to the rapidly cooling surface of a static magma. This fabric can develop in the chilled margins of dykes (Dawson and Hargraves, 1985) and may form in an analogous way to spinifex texture in komatiites.

8.4.3 Phenocryst Orientation Under Magma Flow

Sparsely distributed phenocrysts in flowing dyke magma should rotate in specific patterns according to the theoretical and experimental work of Jeffery (1922), Taylor (1923) and Ramsay (1967). Individual particles continually change their orientation under continued shear, but a population of grains develops a specific average orientation with respect to the plane of the dyke and the direction of flow (Fig. 8.3). This average orientation changes with the amount of shear strain. For low values of shear strain where particles have rotated less than approximately a hundred times, the average long axis of particles will align in the direction of flow, while the average short axis will be perpendicular to the dyke plane.

Under greater shear strain and a larger number of rotations (more than a few hundred) the average long axis will be aligned perpendicular to the flow direction but still within the flow plane (Ramsay, 1967; Reed and Tryggvason, 1974; Dawson and Hargraves, 1985).

The amount of shear which produces a few hundred rotations (marking the transition between the two types of fabric) depends on the shape anisotropy of phenocrysts (Fig. 8.4). An estimate of $R = 1$ implies no anisotropy, but can be used as an upper limit on the calculation; it maximizes the number of rotations resulting from a minimum amount of shear strain. Using $R = 1$, the shear strain required to produce a few hundred rotations is calculated to be approximately 5000. (Using values of R which are not equal to 1 will result in larger values of shear strain.) A shear strain of 5000 is equivalent to a downstream flow of a few kilometers over a dyke half-width of 1 meter and tens of kilometers for a dyke half-width of 20 m.

Owing to the uncertainty in the details of emplacement of the GAD magma (e.g. flow rates, extent of multiple intrusion, and cooling rates), it is not presently possible to calculate the distance of subliquidus shear flow. Therefore, the type of flow fabric cannot be calculated. Nevertheless, the fabric to be expected can be assessed through an empirical approach.

8.4.4 Examples of Fabrics Controlled by Magma Flow

In several studies, the observed fabric can be related to a known magma flow direction and in most cases the maximum AMS axis is

observed to align in the direction of flow. Several examples follow:

In a sill from near Spitsbergen, Norway, the maximum AMS axes point in the direction of a probable feeder (Halvorsen, 1974). In the margins of dykes from the Koolau Complex, Oahu, Hawaii, the maximum axes are observed to parallel surface lineations which trend in the flow direction (Knight and Walker, 1988). The AMS fabric of lava flows was also investigated using an analogue material. A mixture of 2% nickel-filings disseminated throughout a plaster-of-Paris matrix was used and it was found that the maximum AMS axes approximate the direction of flow (Wing-Fatt and Stacey, 1966). Other studies indicate simply that elongate particles are aligned in the direction of flow. These studies include phenocrysts in andesitic dykes (Smith, 1987) and felsic ash flow sheets (Rhodes and Smith, 1972), and also sand grains in flowing water (Rusnak, 1957).

Less frequently, the intermediate axis points in the direction of flow. Khan (1962) presented evidence from 9 Tertiary lava flows indicating intermediate axis alignment in the direction of flow. Ellwood (1978) also studied various basaltic dykes in Iceland and concluded that intermediate axes lie in the direction of flow. However, there are no independent textural features giving flow direction in the dykes of Ellwood's study, and Ellwood's AMS data has been interpreted differently by Dawson and Hargraves (1985) and Dawson (pers. comm, 1988). Ellwood's sites in which both the intermediate and maximum axis lie in the dyke plane (sites DD and ED in Ellwood, 1978) are re-interpreted by Dawson and Hargraves such that maximum rather

than intermediate AMS axes are aligned in the direction of flow.

In general, therefore, the maximum AMS axes in mafic rocks are observed to align in the direction of flow with the result from Khan (1962) providing the only probable exception.

8.4.5 Interacting Particles (Imbrication)

If phenocrysts are very abundant and interact, then the fabric is determined by intergranular collisions. Phenocrysts will acquire orientations which minimize the angular momentum transferred during collisions as the phenocrysts are sheared past each other (Rees, 1979). As a result, phenocrysts can be imbricated in the shear plane as much as 30° out of the flow direction (Rees, 1979). This effect may be especially pronounced adjacent to dyke margins (Blanchard, et al., 1979).

8.4.6 Examples of Imbrication During Flow

In a nickel impregnated plaster-of-Paris analogue, Wing-Fatt and Stacey (1966) observed that the maximum AMS axes were frequently imbricated at an angle of approximately 12° to the plane of flow. In their study of the dykes of the Koolau Complex, Hawaii, Knight and Walker (1988) found most dykes to have an imbrication angle of $0-25^{\circ}$ with respect to the plane of the dyke. Furthermore, Knight and Walker (1988) showed that the sense of imbrication on opposite sides of the dykes was symmetrical and unambiguously gave the polarity of magma flow as well as the axis of flow.

Other studies show that elongate particles can be imbricated with dip direction towards the source. This is shown for phenocrysts in felsic ash-flow sheets (Rhodes and Smith, 1972) and sand grains in flowing water (Rusnak, 1957).

8.4.7 Deformation Late in the Cooling History

The AMS fabric can also be acquired late in the cooling history when the magma has stopped flowing and has begun to behave plastically. At this stage it will adjust its shape so as to be in mechanical equilibrium with its host (Pollard, 1987) and any change in shape of the magma body will cause reorientation of entrained rigid particles, i.e. the already-formed crystals. Under pure shear strain the maximum axes of rigid ellipsoidal grains will rotate towards the direction of elongation and will become parallel to it after a large amount of strain (Gay, 1968; Reed and Tryggvason, 1974). Furthermore, the minimum axis will rotate towards the direction of shortening. In addition, any magnetite crystals growing at this stage will align with long axis in the direction of elongation and short axes will align in the direction of shortening (Ellwood, 1979)

A fabric may also be acquired by contraction during cooling, i.e. formation of columnar jointing (Ellwood and Fisk, 1977), but this effect is shown to be of secondary importance (Ellwood, 1979).

8.4.8 Examples of Fabric Acquired Late in the Cooling History

Two studies identify the acquisition of an AMS fabric related to the compression caused by the weight of the overlying magma column

(Fig. 8.5). One study is of Icelandic columnar-jointed dykes (Ellwood, 1979), and the other is of the Mealy dyke swarm of the Canadian Shield (Park et al., 1988; Tanczyk, pers. comm. 1988).

8.4.9 Summary

Rocks which crystallize rapidly at the chilled margins may have maximum AMS perpendicular to the dyke margin. More interior parts of the magma which were sheared during flow will have maximum AMS axes either in the direction of flow or transverse to it depending on the magnitude of shear strain. In either case, the minimum AMS axis will be perpendicular to the plane of the dyke. Imbrication can develop if phenocryst interactions during flow are important. After the magma has stopped flowing, it may deform plastically resulting in reorientation of its phenocryst population and a preferred alignment of any still-growing crystals.

8.5 ORIENTATION RESULTS FROM THE GAD

8.5.1 Introduction

The principal axes of AMS data have large scatter but on average have a simple relationship to the orientation of the GAD (Fig. 8.6). Maximum axes are concentrated sub-horizontally in the plane of the dyke. Intermediate axes are scattered but tend to have steep inclinations in the plane of the dyke. Minimum axes are concentrated in the direction perpendicular to the dyke plane (horizontal- to shallow-dipping).

Data are grouped by traverse in Fig. 8.7 and summarized in Figs. 8.8 and Table 8.1. The data in Fig. 8.8 have been adjusted to a common strike of 70° and a vertical dip in order to correct for differences in the local trend and dip of the dyke. Although the site means are calculated from rather scattered data (reflected in many large values for angular dispersion in Table 8.1), the site means can be divided into four meaningful groups each of which has a distinct AMS fabric and corresponds to distinct parts of the dyke.

8.5.2 Near-Margin Samples

Some dyke-margin and satellite dykelet samples from unit 1 have the maximum AMS axis perpendicular to the dyke plane. Samples A, from traverse 5, A, P and Q from traverse 7, and perhaps A-G from traverse 14 are examples of this. The chilled margin samples from traverse 15 do not have this fabric.

An AMS maximum axis perpendicular to the dyke plane is thought to result from rapid crystallization favoring mineral growth perpendicular to the cooling surface (Dawson and Hargraves, 1985) (see Section 8.4.2).

8.5.3 Unit 1

Unit 1 samples from traverses 7, 10, 12, 14, 15 and 16 typically have maximum AMS axes sub-horizontal in the plane of the dyke and minimum axes perpendicular to the dyke plane. At each of these traverses, the dyke-dip is closely matched by the inclination of the minimum AMS axis. In particular, ground magnetic data (Table 11.4)

indicate that at traverses 12, 14, 15 and 16 the dyke dips at 90° , 70° - 80° S, 90° and 80° - 85° N, respectively. These dips are reflected by the AMS data. The principal AMS axes are most tightly grouped at traverses 15 and 16 with an angular scatter of less than 10 degrees in both cases.

The AMS fabric in these unit 1 rocks is thought to have been acquired during magma flow, in which case the flow trajectory would be interpreted to be vertical or horizontal depending on the amount of strain (Section 8.4.3). As most observations indicate that long axes of phenocrysts align in the direction of flow (Section 8.4.4), it is considered likely that unit 1 magma was injected along a sub-horizontal trajectory.

Field evidence for nested multiple intrusion (Section 2.2.6) suggests that samples from the dyke interior record a later period of flow than do near margin samples. GAD samples from near the margin tend to give approximately the same AMS fabric as samples located towards the dyke interior, and therefore it may be concluded that the flow direction remained similar throughout the cooling history of unit 1 rocks.

8.5.4 Unit 1: Southwest End of the Dyke

Unit 1 samples from traverses 2, 3 and 4 tend to have maximum axes sub-horizontal in the plane of the dyke and poorly-defined minimum and intermediate axes. The minimum axes tend to be steeply oriented and cannot be related to the dyke dip (Section 11.4). These

data are interpreted as a separate fabric type. This fabric is the same as that in the Mealy dyke swarm (Park et al., 1988) and may have the same origin, i.e. plastic deformation at a late stage of cooling (Fig. 8.5). The fact that this fabric is restricted to the southwest end of unit 1 suggests that this part of the dyke has different characteristics. This end is nearest to the Keweenawan rift system of comparable age and may represent a deeper exposure level than farther west caused by regional block tilting of a few degrees (Figs. 1.1 and 12.1 and Table 12.1 and Section 12.3).

8.5.5 Unit 2

The data from unit 2 samples are grouped together (Fig. 8.8). Maximum axes are parallel to the dyke plane and are generally sub-horizontal. The minimum axes are typically perpendicular to the dyke-plane. In addition, unit 2 data from north and south sides of the dyke at each traverse, group separately (Fig. 8.8). The AMS fabric of unit 2 rocks can be partly related to the feldspar foliation observed throughout unit 2 but mapped in detail at traverse 7.

Unit 2 rocks at traverse 7 exhibit a synformal foliation defined by aligned feldspar laths (Figs. 2.3 and 2.4 and Section 2.2.3). At traverse 7, the AMS fabric parallels the feldspar fabric on the north and south limbs but not in the trough region of the synformally distributed foliation pattern.

The reason for the sub-horizontal alignment of the maximum AMS axes at traverses 7, 7', 10 and perhaps 11 is unknown. It is not

explained by any obvious feldspar lineation within the foliation plane.

8.6 CONCLUSIONS

The principal conclusions of the AMS study of the GAD are the following:

1) The degree of anisotropy is low, about 2 - 4%. Samples tend to be more foliated than lineated. There are no differences between unit 1 and 2 samples in degree of anisotropy or in the shape of the susceptibility ellipsoid.

2) Although the data tend to be rather scattered, there are four distinct AMS fabric-types present in rocks of the GAD. In each case the AMS fabric is considered to mimic the rock fabric.

(a) Chilled margin samples often exhibit a maximum AMS axis perpendicular to the dyke contact; this fabric is considered to be due to rapid crystallization.

(b) The principal AMS axes of most unit 1 samples have a simple orientation with respect to the dyke plane. The maximum AMS axes typically lie horizontally in the plane of the dyke, the intermediate axes are vertical and the minimum axes are perpendicular to the plane of the dyke. This fabric is best developed at the most northeasterly traverses (15 and 16) and is interpreted to result from sub-horizontal magma flow.

(c) At the southwest end of the dyke, samples of unit 1 exhibit a fabric characterized by maximum AMS axes which lie horizontally in the

plane of the dyke and minimum axes with steep inclination. This AMS fabric was probably acquired late in the cooling history when the magma had stopped flowing and was being deformed plastically.

(d) The orientation of the magnetic susceptibility ellipsoid in unit 2 rocks appears to conform with a synformally distributed feldspar foliation.

Fig. 8.1: F-L diagram. F and L measure the degree of oblateness and prolateness, respectively, of the susceptibility ellipsoid and are calculated from the lengths of its principal axes, K_1 , K_2 and K_3 . Data is from Table A9.1.

Fig. 8.2: P-T diagram. P measures the degree of anisotropy and T measures the shape of the ellipsoid. P ranges from 1 (no anisotropy) to infinity (maximum anisotropy). For $T = -1$, only lineation is present. For T between -1 and 0 , lineation is dominant. For $T = 0$, the rock is equally lineated and foliated. For T between 0 and 1 , foliation is dominant. For $T = 1$, only foliation is present. Data is from Table A9.1.

Fig. 8.3: Orbits of uniaxial ellipsoidal particles undergoing simple shear (after Ramsay, 1967, pp. 222 and 224). The flowplane is Y-Z, and the flow direction is Y. 'a' is the unique axis and 'b' is the equatorial axis. $R = a/b$. On each diagram the orbit of the a-axis is illustrated. In (B), the speed of motion of the a-axis around the orbits is indicated by the number of arrows; triple arrows mean a fastest rotation rate.

Fig. 8.4: Shear strain as a function of particle rotation:
 (A) Relationship between shear strain and rotation angle, ψ . Curves after Ramsay (1967, p. 223).
 (B) The relation between shear strain and along-dyke transport distance. R is defined in Fig. 8.1.

Fig. 8.5: Explanation of late-stage plastic deformation of the magma. Diagram after Park et al. (1988). σ_1 , σ_2 and σ_3 are the principal stresses interpreted to be present after the dyke has cooled and crystallized sufficiently to be able to support internal stresses. Under this configuration, the magma is compressed vertically and squeezed out along strike.

Fig. 8.6: Distribution of maximum, intermediate and minimum principal directions of AMS data from the GAD. Data from 281 specimens (from 112 samples) are plotted on the lower hemisphere of equal-area stereonet. Data are tabulated in Table A9.1. The data are contoured using the counting net of Kalsbeck (1963). Black regions contain a data point density of 4-6% per 1% area. Dotted areas have a point density of 3%. Outlined areas have a point density of 2%. Average trend of the GAD is plotted on each contoured diagram.

(Continued on next page)

Fig. 8.6

Fig. 8.6

(Continued on next page)

Fig 8.6

Fig. 8.7: AMS data from the GAD grouped by traverse. Traverse locations are given in Fig. 1.3. Square/triangle/circle symbols locate the maximum/intermediate/minimum axes of the AMS ellipsoid sample-averages (Table A10.2) plotted on the lower hemisphere of equal-area stereonets. The trace of the dyke-plane is also plotted on the lower hemisphere; a dashed line is used when the dip is uncertain. Some groups of data (e.g. from samples of satellite dykelets) are enclosed by a line. Letters superimposed on symbols are keyed to the sample numbers (lower left corner) and the location map (lower right corner). The location map for each traverse shows the across-dyke position of each sample; host rock is indicated by the horizontally-ruled pattern. North is to the right on each location map.

Fig. 8.7

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Fig. 8.7

(Continued on next page)

TRAVERSE 4

Fig. 8.7

Fig. 8.7

Fig. 8.7

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Fig. 8.7

Fig. 3.7

Fig. 8.7

Fig. 8.7

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Fig. 8.7

Fig. 8.7 (continued)

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Fig. 8.7

Fig. 8.7

Fig. 8.8: Site summary of AMS data (from Table 8.2) for units 1 and 2. Data points are labelled by sample traverse, and, for the unit 2 data, whether the data is from the north limb (N), south limb (S) or trough (T) of the synform defined by the feldspar foliation. Squares/circles locate maximum/minimum axes of the AMS ellipsoid site averages. Data are plotted on the lower hemisphere of equal-area stereonets. All data have been rotated to correspond to a common orientation of the dyke, i.e. a strike of 70° and vertical dip.

Fig. 8.8

Fig. 8.8

Table 8.1: AMS site averages calculated using the axis-averaging technique

Sample Number	Mean Suscept.	K ₁		K ₂		K ₃		Angular Dispersion		
		Maximum Dec.	Axis Inc.	Intermed. Dec.	Axis Inc.	Minimum Dec.	Axis Inc.	C ₁	C ₂	C ₃
GROUP A	18138	243.9	6.7	326.6	4.2	350.5	61.2	20	54	52
GROUP B	13913	161.1	4.2	38.0	82.3	251.5	6.3	—	—	—
GROUP C	52766	269.0	56.4	56.1	32.6	156.6	18.1	24	30	27
GROUP D	12788	316.2	46.8	41.3	12.9	139.3	33.3	63	57	58
GROUP E	20006	280.3	18.6	184.2	16.9	58.2	68.6	35	37	30
GROUP F	44512	290.4	46.9	77.3	23.1	174.3	24.4	60	43	42
GROUP G	18816	351.5	12.5	243.6	54.8	90.0	32.2	—	—	—
GROUP H	13960	183.7	5.2	262.8	15.0	93.9	75.9	38	38	33
GROUP I	30400	90.6	27.5	191.7	21.0	313.6	51.2	24	11	24
GROUP J	29256	71.9	11.5	246.4	74.3	342.1	4.1	23	43	36
GROUP K	38201	63.2	11.2	162.2	46.3	323.8	42.3	37	41	18
GROUP L	43321	76.4	35.8	207.2	32.1	320.3	39.4	41	52	0
GROUP M	19382	261.2	19.3	56.1	59.7	165.6	1.2	28	47	45
GROUP N	19501	203.5	29.7	325.9	20.2	29.6	66.6	40	59	57
GROUP O	34243	107.3	66.0	15.0	6.3	282.2	26.9	14	28	30
GROUP P	22565	251.8	26.6	76.2	65.4	336.4	1.7	40	42	24
GROUP Q	18355	43.7	22.8	312.6	2.8	210.7	62.8	26	37	32
GROUP R	23007	85.1	20.9	189.0	27.5	320.9	56.2	49	50	8
GROUP S	11462	250.1	7.6	196.2	44.5	318.9	24.9	57	56	45
GROUP T	35607	243.2	11.1	69.6	71.9	327.4	4.9	40	47	27
GROUP U	31342	351.0	12.2	79.3	39.3	263.6	35.7	43	47	50
GROUP V	32788	91.8	23.4	225.4	56.8	350.2	26.3	36	36	14
GROUP W	46707	200.0	57.9	85.7	14.2	347.3	26.0	—	—	—
GROUP X	9312	206.4	37.2	79.7	33.7	322.9	41.4	51	51	39
GROUP Y	37964	7.4	78.7	266.0	2.0	175.3	11.0	—	—	—
GROUP Z	27220	97.6	18.0	269.6	71.9	6.3	2.0	14	14	8
GROUP AA	35352	269.3	12.1	40.9	72.0	176.2	13.4	11	11	8

Mean Susceptibility is the bulk susceptibility per unit volume and is measured in 10^{-6} SI units.

Declination and Inclination give the orientation of each of the three principal axes, K₁, K₂ and K₃.

$C_i = \arccos(S_i)$ where $S_i = I_{\max} / (I_{\max} + I_{\min})$ and $I_{\max}$, $I_{\min}$ and I_{int} are the eigenvalues of the orientation tensor calculated for the i^{th} principal axis (Schmidt et al., 1988)

(Continued on next page)

Table 8.1

GROUP	A	B	C	D	E	F	G
TRAVERSE	Unit 1	Unit 1	Unit 1	Unit 1	Unit 1	Unit 1	Unit 1
DESCRIPTION	Interior	margin	satellite dykelet	Interior	Interior	dykelet +sat. dykelet	satellite dykelet
SAMPLES	REB42803 REB42804 REB42801 REB42802 REB42805 REB42810	REB42811	REB42815 REB42812 REB42813	REB42510 REB42509 REB42507 REB42506 REB42505 REB42504 REB42503 REB42502 REB42501	REB42403 REB42404 REB42405 REB42402 REB42401 REB20416B	Unit 1 dykelet +sat. dykelet REB20421 REB20416B	Unit 1 satellite dykelet REB20420
GROUP	H	I	J	K	L	M	N
TRAVERSE	Unit 1	Unit 1	Unit 2	Unit 2	Unit 2	Unit 2	Unit 1
DESCRIPTION	margin	Interior	south limb	trough	north limb	south limb?	margin
SAMPLES	REB40125 REB40126 REB40140 REB40142	REB40130 REB40138	REB40127 REB40128 REB41029 REB40145 REB40131 REB40132	REB40133 REB40134 REB40135	REB40136 REB40137	REB61105 REB61104 REB61103 REB61102 REB61101	REB21701 REB21702 REB21703 REB21704 REB21705
GROUP	O	P	Q	R	S	T	U
TRAVERSE	Unit 2	Unit 1	Unit 2	Unit 2	Unit 2	Unit 1	Unit 1
DESCRIPTION	north limb?	Interior	trough	north limb	north limb	Interior	satellite dykelet
SAMPLES	REB21601 REB21602 REB21603 REB21604 REB21605	REB21201 REB21202 REB21203 REB21204	REB21101 REB21102 REB21103 REB21104 REB21005	REB21001 REB21002 REB21003 REB21004 REB21005	REB20106 REB20107 REB20108 REB20109 REB20110	REB63305 REB63304 REB63303 REB63302 REB63301	REB41808 REB41807 REB20710 REB20712 REB20713 REB41810 REB20711
GROUP	V	W	X	Y	Z	AA	
TRAVERSE	Unit 1	Unit 2	Unit 2	Unit 1	Unit 1	Unit 1	
DESCRIPTION	Interior	south limb	trough & north limb	margin	Interior	Interior	
SAMPLES	REB41804 REB41803 REB41822	REB41802	REB41816 REB41801 REB41817 REB41818 REB41811	REB20705	REB20813 REB20814 REB20815 REB20816	REB20910 REB20907 REB20911 REB20908 REB20909 REB20912	

CHAPTER 9

PALEOMAGNETISM

9.1 INTRODUCTION

The paleomagnetic study of the Great Abitibi Dyke (GAD) was used to identify the primary thermal remanent magnetization (TRM) direction acquired during cooling of the dyke magma and to determine whether the remanence direction varies along and across the dyke. Systematic variation can be interpreted in terms of: 1) paleosecular variation during differential cooling of the dyke, between the margins and the interior of the body, or as a consequence of multiple intrusion, and 2) post-cooling, block-tilting of the dyke.

The characteristic remanent magnetization and any secondary components were identified through a process of progressive demagnetization and measurement of the remanent moment after each level of demagnetization. Two demagnetization techniques were used: thermal demagnetization and alternating field demagnetization. Both techniques are discussed in Appendix 8.3.

9.2 THERMAL DEMAGNETIZATION

Thermal demagnetization up to 600°C was carried out on seven specimens from seven independently oriented samples (Figs. 9.1 and 9.2). These were chosen to provide a representative cross-section of the dyke at traverse 7 and also because they contained no low-coercivity viscous overprints.

Under thermal demagnetization, magnetic intensities decayed to

<1% of their original intensity by 580° C. Six of the seven demagnetization curves are nearly identical. They are square-shouldered and indicate loss of >90% of their intensity between 530° C and 580° C. In detail, however, a slight and consistent change in magnetization direction occurred in all samples during thermal demagnetization over the temperature range 20° to 500°C (Fig. 9.2). The removed direction was a viscous overprint contributed by the present Earth's field (PEF).

The Curie point is the temperature above which the spontaneous magnetization exhibited by ferromagnetic minerals (also ferrimagnetic and canted antiferromagnetic minerals) is destroyed by thermal agitation (McElhinny, 1973, p. 35). Curie point determinations can be used to identify the minerals which host the magnetic remanence. Rocks of the GAD contain 5-15% iron oxides consisting of ilmenite and titanomagnetite (Chapter 2). The Curie point for minerals of the hematite-ilmenite series varies linearly with composition from 680°C for pure hematite to -200°C for pure ilmenite (McElhinny, 1973, p. 44). For minerals of the magnetite-ulvospinel series, the Curie point varies roughly linearly from 580°C for pure magnetite to lower than -100°C for pure ulvospinel (McElhinny, 1973, p. 42; Smith and Prevot, 1977).

Accurate determination of the Curie point requires a Curie balance. However, an estimate of the Curie point can be obtained from the unblocking temperature spectrum (Fig. 9.1). The blocking temperature of magnetic grains is the temperature at which a magnetic

remanence direction is 'frozen in' upon cooling. Therefore, the blocking (unblocking) temperature for a given mineral will always be equal to or less than the Curie temperature.

The sharp drop in intensity between 520° and 580° C implies a Curie point no lower than 580°, the value for nearly pure magnetite. This Curie point also corresponds to the composition along the ilmeno-hematite series, Ilm_{10} , close to hematite in composition. However, no hematite is present. Therefore, the carrier of the magnetic remanence must be magnetite (Usp_0). On the other hand, compositional analyses of titanomagnetite grains (Chapter 4) reveal distinctly different compositions, Usp_{30-60} .

It is possible that the magnetic remanence is hosted in portions of titanomagnetite grains (not analyzed) which have exsolved ilmenite lamellae and thereby become enriched in magnetite component (Strangway et al., 1968; McElhinny, 1973, p. 52, and references therein). However, most investigators consider the source of remanence in igneous rocks to be single domain magnetite inclusions in feldspars and mafic silicates (Buchan, 1979; Tarling, 1983, p. 55; Geissman et al., 1988). The source for the magnetic remanence in rocks of the GAD remains to be determined.

9.3 ALTERNATING FIELD DEMAGNETIZATION

Alternating field demagnetization was carried out on two or three specimens from each of 146 samples. Representative demagnetization curves and orthogonal vector plots are given in Fig. 9.3 and 9.4. These illustrate that, in general, only a single magnetization

component is present in each sample. Any viscous overprint is usually removed by 25 mT. The magnetization of many samples becomes unstable in cleaning fields above 60 mT.

Remanence directions were defined from the demagnetization curves using a procedure modified from Kirschvink (1980) and detailed in Section A8.3. Paleomagnetic data are summarized in Fig. 9.5, Tables 9.1 and 9.2 and Appendices 9 and 10. The standard approach of Fisher (Fisher, 1953) was used to average remanence directions; first, the data from specimens were averaged into sample means which were then averaged into site means. Details are given in Section A8.3.

The characteristic remanence direction revealed by the alternating field technique has a west-northwest strike and intermediate to steep downward dip. The remanence direction revealed by the alternating field technique is identical to that revealed by thermal demagnetization and is similar to that isolated by Fahrig et al. (1965) and Larochelle (1966) in their reconnaissance-scale study of the Abitibi swarm.

9.4 MAGNETIZATION DIRECTIONS OF UNITS 1 AND 2

Petrographic and chemical studies of the GAD distinguished two distinct units, 1 and 2. Unit 1 was emplaced first throughout the dyke and unit 2 was located in the dyke interior over approximately half of the dyke length (Figs. 3.4 and 3.5). Unit 2 can be interpreted to represent a second magmatic pulse into unit 1 (Sections 2.2.6 and 6.4).

The paleomagnetic remanence data are consistent with this

interpretation. The samples from traverses 2, 3, 4, 15 and 16, contain only rocks of unit 1 and have remanence directions that differ slightly from unit 1 and 2 samples of traverses 5, 7, 7', 9, 10, 10', 11, 12 and 14. A possible interpretation is that the samples of unit 1, from traverses where both unit 1 and 2 are present, were magnetically overprinted by the intrusion and cooling of unit 2 material.

The time interval required for unit 1 magma at traverse 7 (half thickness ~30 m) to have cooled below the Curie point (and acquired a remanence direction) in the dyke margin area is approximately 50 to 100 years (see Fig. 3 in Delaney, 1987). This represents a minimum estimate of the time interval between intrusion of unit 1 and 2.

The contact between unit 1 and 2 is not marked by a grain size change, an observation indicating that unit 1 rocks were still 'warm' when unit 2 magma was intruded. This cannot be explained by a high ambient temperature of the host rocks since unit 1 is fine-grained to chilled at its contact with host rocks. The absence of a grain size change at the unit 1 - unit 2 contact must therefore indicate a relatively short cooling time between intrusion of units 1 and 2. As a maximum estimate of this time interval, unit 1 will have cooled to temperatures of only a couple hundred degrees after several hundred years (Fig. 3 in Delaney, 1987).

Variation in palcomagnetic direction on the time-scale of a hundred to a few hundred years is termed paleosecular variation and results from short excursions of the magnetic pole about the mean axial dipole (McElhinny, 1973, pp. 19-20).

9.5 BAKED CONTACT TESTS

The unit 1 and 2 remanence directions isolated during alternating field and thermal demagnetization are considered characteristic of the GAD. It remains to be shown that these are thermal remanent magnetization (TRM) directions acquired during initial cooling of the magma, rather than later overprints.

To demonstrate that the unit 2 direction is a primary TRM, samples of adjacent host rock were tested in two locations for thermal overprinting caused by the dyke (Everitt and Clegg, 1962). At both localities, the test was done using an intersecting Hearst-Matachewan dyke. At traverse 10' (Figs. 9.5 and 9.6) samples were taken 370 metres from the nearest contact of the GAD and these samples showed the characteristic direction of the older Hearst-Matachewan dyke swarm (Irving and Naldrett, 1977). Other samples from the same Hearst-Matachewan dyke were taken adjacent to the GAD and showed the characteristic direction of the GAD (Fig. 9.5 and 9.6). The other intersection was at traverse 5, where three samples, located 240 metres from the nearest contact of the GAD, show the characteristic direction of the Hearst-Matachewan swarm, while samples from the same Hearst-Matachewan dyke adjacent to the GAD, showed the characteristic magnetization direction of unit 2. Both baked contact tests indicate that intrusion of the dyke has thermally overprinted the adjacent Hearst-Matachewan dyke host rock with the characteristic unit 2 direction. Therefore, the unit 2 direction is a primary TRM.

There is no baked contact for the unit 1 magnetization direction.

However, since the regional distribution of unit 1 and 2 remanence directions correlates with the distribution of unit 1 and 2 rocks, the most straightforward interpretation is that both unit 1 and 2 magnetizations are primary TRMs.

9.6 POST-INTRUSION TILTING

The scatter in unit 1 and unit 2 palcomagnetic data (Fig. 9.6) may partly be due to post-intrusive tilting of the dyke and host terrane. This was tested by considering the block rotations about horizontal axes required to produce tighter groupings of the palcomagnetic data from traverses 2, 3, 4, 5, 11 and 16 and evaluating these in terms of the regional geology (Figs. 9.7 and 9.8). The proposed tectonic corrections are between 10° and 15° .

Data from traverse 2 were rotated about a north-south axis implying block tilting to the west, a model consistent with crustal loading caused by east verging thrusting of the nearby Kapuskasing Structural Zone (Percival and Card, 1983) (Fig. 1.1). The near-vertical dyke dip (Table 11.4) argues against rotation about an E-W axis.

Evidence from field mapping and aeromagnetic modelling (Table 11.4) reveals that at traverses 3, 4 and 5, the dyke now dips to the north at 70° to 80° . Restoration of dyke dip at these traverses to vertical by rotation about an east-southeast axis makes the palcomagnetic directions from these traverses conform more closely to the other palcomagnetic data.

At traverse 11, the GAD dips to the south (70° - 80°) and has a

trend of 20° , which is different than the characteristic dyke trend of 70° . In the vicinity of this traverse (#11), the trend of the dyke is slightly sinuous. Johnstone (1987, pp. 253-254) suggests that the variation in the dyke-trend results from minor late Proterozoic deformation, which generated gentle, open folds plunging to the southwest. The model proposed in Fig. 9.7, of a rotation about a southeast-trending horizontal axis, is consistent with the paleomagnetic data, but may be too simple because it does not include a component of rotation about a vertical axis as implied by Johnstone's model.

The slight northward displacement of the remanent direction of traverse 16 from the interpreted paleomagnetic path (Fig. 9.6) may also be due to post-intrusive tilting. At this location the dyke is thought to dip to the north at 80° to 85° . Restoration of the dyke dip to vertical brings the paleomagnetic remanent direction into a tighter grouping with data from other traverses.

The paleomagnetic data from the remaining traverses, 7, 7', 9, 10, 10', 12, 14 and 15, are very tightly grouped without tectonic correction. These traverses, showing no paleomagnetic evidence for block tilting, are all located in the interior of the Abitibi belt, while the block-tilted traverses (i.e., 2, 3, 4, 5, and 16, excepting 11) are located towards the ends of the Abitibi belt, near the Kapuskasing Structural Zone and the Grenville Orogen, both of which show evidence of ~1100 Ma tectonic activity.

9.7 POSITION ALONG THE APWP

Pole positions were calculated from traverse means and are plotted on the apparent polar wander path (APWP) for North America (Fig. 9.9). The average pole position for each traverse may partially average out paleosecular variation, but the best estimate of the geomagnetic pole position (of the axial dipole at the time of unit 1 and unit 2 cooling) is given by the averages of unit 1 and unit 2 pole positions. Tectonically corrected and uncorrected poles fall near the the Logan loop between 1100 and 1260 Ma, and provide a well-defined position along the APWP which is accurately dated at 1140 ± 2 Ma (age from Krogh et al., 1987).

9.8 CONCLUSIONS

The principal conclusions of the palcomagnetic study of the GAD are:

- 1) The characteristic remanence directions are TRMs acquired during cooling of unit 1 and 2 magma pulses.
- 2) Unit 2 was emplaced only a short time (perhaps less than a hundred years) after unit 1.
- 3) Post-intrusion tilting at traverses 2, 3, 4, 5, 11 and 16 may be responsible for some of the scatter in remanent magnetization directions.
- 4) Virtual geomagnetic poles of age 1140 Ma BP, derived from units 1 and 2, plot along the Logan Loop of the North American APWP.

Fig. 9.1: Normalized thermal decay curves for samples from traverse 7. (C) summarizes the results in (A) and (B). The location map (D) shows the across-dyke position of each sample. Host rock is indicated by the horizontally-ruled pattern. North is to the right on the location map.

Fig. 9.2: Stereonet plot of thermal demagnetization data from traverse 7. Sample locations are the same as in Fig. 9.1. Data are plotted on equal-area stereonets. All data are plotted on the lower hemisphere. Large circles are partial thermal remanent magnetization directions removed between 20° and 400-500°C. Small circles are the characteristic remanence directions reached at temperatures above 500°C. The large triangle marks the present Earth's field (PEF) magnetization direction.

Fig. 9.3: Normalized AF decay curves for samples from traverse 7. Sample locations are the same as in Fig. 9.1.

Fig. 9.4: Orthogonal component and equal-area stereonet plots for the AF demagnetization data in Fig. 9.3. Sample locations are the same as in Fig. 9.1.

Fig. 9.4

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Fig. 9.4

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Fig. 9.4

Fig. 9.5: Stereonet plots of paleomagnetic data grouped by traverse. Solid/open symbols are plotted on the lower/upper hemisphere of equal-area stereonet. Dots denote samples from the dyke. Triangles are from host rock samples. Each data point is a sample mean and was averaged from specimen data using the averaging technique of Fisher (1953). Specimen data is tabulated in Table A9.1 and sample averages are listed in Table A10.1. The location map (below stereonet) shows the across-dyke position of each sample. Host rock is indicated by the horizontally-ruled pattern. North is to the right on each location map. To facilitate inter-traverse comparison, the plotted remanence directions of all samples have been recalculated for a common location, 81.4°W and 48.5°N.

4

Micro-D

Fig. 9.5

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Fig. 9.5

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Fig. 9.5

Fig. 9.5

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Fig. 9.5

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Fig. 9.5

Fig. 9.5

Table 9.1: Summary of paleomagnetic data

Traverse	Site	Numbers	Sample N ¹	Mean Dec. ²	Mean Inc. ²	Alpha 95 ³	k ⁴
2	RE8428	1,2,3,4,5, 12,13,15	8	275.1	64.6	5.2	115
3	RE8425	1,2,3,4,5, 6,7,9,10,11 ⁵	10	292.9	53.0	6.0	65
4	RE8424	1,2,3,4,5	12	288.6	57.1	4.8	82
	RE8204	16A,16B,17, 18,19,20,21					
5	RE8203 ⁶	1 ⁵ ,2 ⁵ ,5,6,7	5	310.1	65.7	6.1	160
7	RE8401	25,26,27,28, 29,30,31,32, 33,34,35,36, 37,38,40,42, 43,45,47,48 ⁵ , 49 ⁵ ,52 ⁵	22	294.8	70.3	3.1	99
7'	BX8611	1,2,3,4,5	5	298.9	65.0	3.4	518
9	BX8217	1,2,3,4,5	10	285.1	69.8	5.9	67
	BX8216	1,2,3,4,5	22	315.2	73.6	2.5	160
10	BX8210	1,2,3,4,5					
	BX8211	1,2,3,4					
	BX8212	1,2,3,4					
	BX8213	1 ⁵ ,2 ⁵ ,3 ⁵ ,4 ⁵					
	RE8202	1 ⁵ ,3,6,7,9	4	295.2	75.8	1.6	3334
10'	BX8214 ⁷	1 ⁵ ,2 ⁵ ,3 ⁵ ,4 ⁵					
11	RE8201	7,8,9,10	4	328.9	71.7	7.1	169
12	BX8633	1,2,3,4,5	5	300.6	75.8	4.9	244
14	RE8418	2,3,4,5 ⁵ ,7, 8,9 ⁵ ,10,11, 16,17,18,22	16	304.7	71.4	3.6	104
	RE8207	5,12,13	4	273.6	54.0	5.5	277
15	RE8208	13,14,15,16					
16	RE8209	7,8,9,10,11,12	6	280.4	58.4	2.9	547
5	RE8203 ⁶	8,9,10	3	219.1	-16.9	18.2	47
10'	BX8215 ⁷	1,2,3,4	4	212.3	-8.5	7.5	150

¹ Number of samples used in calculation of remanence direction

² All average directions are calculated for a common site, 48.5°N, 81.4°W.

³ Radius of 95% confidence circle (Fisher, 1953)

⁴ Precision parameter (Fisher, 1953)

⁵ 'Baked' host rock samples showing remanence direction of the GAD.

⁶ At site RE8203, samples 1, 2, 8, 9 & 10 all probably belong to the same Matachewan dyke. Samples 8, 9 & 10 are from a site distant from the GAD and show the typical remanence direction of the Matachewan swarm (Schutts and Dunlop, 1981). Samples 1 and 2 are from adjacent to the GAD and were thermally overprinted during cooling of the GAD.

⁷ Sites BX8214 and BX8215 are both located in the same Matachewan dyke. Samples from BX8214 are located adjacent to the GAD and were thermally overprinted during cooling of the GAD. Samples from BX8215 are located more distant from the GAD and show the characteristic remanence direction of the Matachewan swarm (Schutts and Dunlop, 1981)

Table 9.2: Mean palcomagnetic directions

Group	N	Mean Dec	Mean Inc	Alpha95	k	Pole Position	
						lat	long
¹ Unit 1	5	282.3°	57.7°	6.1°	156	35.0°S	29.1°E
² Unit 2	9	303.6°	71.4°	3.6°	205	55.6°S	42.9°E
Tectonically Corrected (See Figure 9.8)							
³ Unit 1	2	276.6°	56.2°	-	-	30.5°	31.0°
⁴ Unit 2	7	298.6°	71.9°	3.6	285	53.1°	45.3°

- ¹ Traverses giving the unit 1 direction are 2, 3, 4, 15 and 16.
- ² Traverses giving the unit 2 direction are 5, 7, 7', 9, 10, 10', 11, 12, and 14.
- ³ Calculated from traverses 15 and 16 (the 'uncorrected' traverses)
- ⁴ Calculated from from traverses 7, 7', 9, 10, 10', 12 and 14 (the 'uncorrected' traverses).

Fig. 9.6: Summary of paleomagnetic site mean data and their alpha95 circle's of confidence (Fisher, 1953). Data points are labelled by traverse number and all data are plotted on the lower hemisphere of an equal-area stereonet. The data is tabulated in Table 9.1. The characteristic directions of the GAD have been divided into two groups, which exhibit either the unit 1 or unit 2 magnetization direction. Data with a shallow southwest direction are from Hearst-Matachewan dykes (Ernst and Halls, 1984) near the GAD but lying outside the zone of reheating caused by intrusion of the dyke. They are part of baked contact tests. To facilitate inter-traverse comparison, the plotted remanence directions of all site means have been recalculated for a common location, 81.4°W and 48.5°N.

Fig. 9.7: Proposed post-intrusive tectonic rotations. Sites 2, 3, 4, 5 and 11 are rotated about a horizontal axis into the directions exhibited by the majority of the unit 1 and unit 2 data. The average magnitude of rotation is about 10° . Each tectonic correction is clockwise (as looking from the southeast). Therefore, the implied post-intrusive rotation is the opposite sense, counterclockwise as looking from the southeast.

Fig. 9.8: Tectonically corrected site mean data. The data in Fig. 9.6 has been rotated by amounts suggested in Fig. 9.7.

CHAPTER 10

BULK MAGNETIC SUSCEPTIBILITY

10.1 INTRODUCTION

This chapter surveys the variation in bulk magnetic susceptibility throughout the Great Abitibi Dyke (GAD) and the results are explained in terms of the variation in titanomagnetite abundance. The susceptibility data are also used to calculate the magnitude of the induced magnetic component, which is compared with that of the natural remanence magnetization (NRM) data from Chapter 9. Both remanent and induced components are considered in choosing an appropriate magnetization direction for use in modelling aeromagnetic and ground magnetic profiles in Chapter 11.

The bulk (or total) susceptibility was measured both per mass and per volume (Ellwood et al., 1988). Bulk volume susceptibility (susceptibility per unit volume), $\underline{K}$, was measured from the samples used for palcomagnetic and AMS analysis (Fig. 1.3). The mass susceptibility (susceptibility per unit mass), $\underline{X}$, was determined from the samples used for chemical study (Fig. 1.2). Ideally, the two approaches should give identical results differing only by the factor of rock density; but since two different sample sets are being used, some differences were expected. All data were collected on a Kappabridge Susceptibility Bridge, KLY-1. The methodology for collecting volume and mass susceptibility data is described in Sections A8.2 and A8.4.

10.2 BULK SUSCEPTIBILITY VS WHOLE-ROCK IRON CONTENT

The source of bulk susceptibility in rocks of the GAD are grains of titanomagnetite (Chapter 2). This fact is reflected by a weak positive correlation between mass susceptibility and whole-rock total Fe content (expressed as wt.% $\text{Fe}_2\text{O}_3\text{T}$) for all samples of the GAD (Fig. 10.1), and by the fact that the most of the Fe_2O_3 in the GAD is hosted in titanomagnetite grains.

The only data which does not follow this trend in Fig. 10.1 are unit 1 samples from satellite dykelets and some chilled margins, whose higher susceptibility results from the superparamagnetic behaviour exhibited by very small titanomagnetite grains at room temperatures (Stacey and Banerjee, 1974, pp. 102-103; Smith and Prevot, 1977).

10.3 REGIONAL VARIATION IN BULK SUSCEPTIBILITY

10.3.1 Introduction

An overview of the regional variation in bulk magnetic susceptibility (Tables A10.1 and A11.1) is provided in Fig. 10.2 (and Tables 10.1 and 10.2). The bulk mass susceptibility data show a considerable range from 94 to 39873 (in units of 10^{-9} SI). The lowest values are from samples of anorthositic gabbro, RE8418.11 and RE8418.01, from traverse 14 (see Fig. 10.2); these samples also have very low contents of iron oxides (Table A2.1). Satellite dykelets and chilled margin samples have the highest susceptibilities (as observed in Section 10.2).

10.3.2 Along-Dyke Variation in Bulk Susceptibility

The possibility of along-dyke variation in bulk susceptibility for both unit 1 and 2 rocks was investigated using both mass and volume susceptibility data as presented in Figs. 10.3 and 10.4. The $\pm 2s$ (standard deviation) error bars illustrate the extreme variability in the data. In light of the large error bars and the small number of data points, any trends must be considered tentative. In unit 1 data, the point values of both volume and mass susceptibility data increase towards the northeast end of the dyke. This trend is slightly better defined in the volume susceptibility data. In unit 2 data, the point values of mass susceptibility decrease towards the northeast. (Volume susceptibility does not show a trend).

These possible along-dyke changes in bulk susceptibility can be related to the longitudinal compositional changes discussed in Chapter 6. A longitudinal increase in bulk susceptibility in unit 1 rocks towards the northeast would correlate with an increasing degree of magma evolution as monitored by incompatible element concentration (Section 6.2.5). The decrease in the susceptibility of unit 2 samples towards the northeast correlates with increasing feldspar content and decreasing mafic mineral (including titanomagnetite) content (Section 6.3).

10.4 HOST ROCK SUSCEPTIBILITY

The susceptibility of the granitic host rock at traverse 7 averages 2500, which is about one third as large as the typical susceptibility of unit 1 rocks and a quarter as large as the typical

susceptibility of unit 2 samples at this site. These granitic host rock samples also have much lower $\text{Fe}_2\text{O}_3\text{T}$ content than rocks of the GAD (Fig. 10.1).

The volcanic host rock (adjacent to the dyke) at traverse 10 has an average susceptibility of 17000 (Fig. 10.1), which is larger than the susceptibility in the dyke. These host rock samples (from traverse 10) are from a zone baked during intrusion of the dyke and the high susceptibilities probably result from the formation of contact metamorphic magnetite during cooling of the dyke. This effect has been noticed in other dykes (e.g. Schwarz et al., 1987).

10.5 KOENIGSBERGER RATIO Q

The induced and remanent contributions to the magnetism of the GAD are assessed in Fig. 10.5. The induced component was calculated from $\underline{K} \cdot \underline{H}$, where $\underline{H}$ is the local geomagnetic field intensity vector, and $\underline{K}$ is the bulk volume susceptibility (using data from Table A10.1). The remanent component is given by the intensity of the natural remanence magnetization (NRM), $|\underline{M}_{\text{NRM}}|$. The relative contributions of the magnitudes of induced and remanent components are assessed by the Koenigsberger ratio, $Q = |\underline{M}_{\text{NRM}}|/|\underline{K} \cdot \underline{H}|$.

Fig. 10.5 shows that, for most samples, the remanent and induced contributions are approximately equal, i.e., $Q \approx 1$. Thus, the remanent component cannot be neglected in aeromagnetic or ground magnetic interpretation. The contribution of both components to the magnetization direction is considered below.

10.6 CHOICE OF MAGNETIZATION DIRECTION FOR MODELLING

Aeromagnetic and ground magnetic profiles across the GAD are modelled in Chapter 11 in order to determine dyke-dip. In modelling magnetic profiles, it is important to know the magnitude and direction of the magnetization vector.

In the case of the GAD, the appropriate magnetization direction must lie somewhere in a roughly elliptical region approximately 40° long and 20° wide which encompasses the induced direction, given by the present Earth's field (PEF), and the range of possible remanence directions (Fig. 10.6). The long axis of the ellipse is oriented parallel to the dyke trend and the uncertainty in magnetic inclination perpendicular to the dyke will be less than $\pm 10^{\circ}$ for magnetization directions chosen from along the dotted line in Fig. 10.6 (Section A12.1). Furthermore, this uncertainty in magnetic inclination is approximately equivalent to the uncertainty in the modelled dip of the dyke.

In modelling magnetic profiles (in Chapter 11), the PEF was used as the magnetization direction. Based on the above analysis, the expected uncertainty in the modelled dips will be approximately $\pm 10^{\circ}$.

10.7 CONCLUSIONS

The principal conclusions of this chapter are:

- 1) Unit 1 and unit 2 samples show scattered trends of increasing bulk magnetic susceptibility towards the northeast and southwest ends of the dyke, respectively. The trends are explained by longitudinal

variation in the abundance of titanomagnetite.

2) Very fine-grained samples from satellite dykelets and the chilled margin of the main dyke exhibit very high susceptibilities which result from superparamagnetic behaviour.

3) The remanent and induced components make approximately equal contributions to the magnetic anomaly produced by the dyke.

4) Uncertainty in the magnetization direction will result in a $\pm 10^\circ$ uncertainty in dyke-dip modelled from aeromagnetic and ground magnetic profiles.

Mass Susceptibility vs. Fe₂O₃ Total

- ▲ Host Rock
- + Satellite Dykelet (Unit 1)
- ◆ Chilled Margin (Unit 1)
- Remaining Samples of Both Unit 1 and Unit 2.

Fig. 10.1: Correlation between mass susceptibility and Fe₂O₃ T (wt%) (all iron expressed as ferric component). Mass susceptibility given in units of 10⁻⁶ SI. Host rock data from traverse 7 are outlined. All other host rock samples are from traverse 10.

Fig. 10.2: Regional variation in bulk magnetic susceptibility (per mass) throughout the Great Abitibi Dyke. Values in 10^{-9} SI units. The centre of each circle marks the location of a sample and the circle diameter corresponds to the magnitude of the susceptibility.

Table 10.1: Mass Susceptibility (Units are 10^{-9} SI)

Traverse	Group	N	Mean Value	Standard Deviation
1	Unit 1	3	6654	1775
2	Unit 1	11	6995	1959
2	Sat. Dykelet	2	14783	3294
3	Unit 1	13	7140	3519
4	Unit 1	6	6542	1557
4	Dykelet+ Sat.Dykelet	3	18095	6583
5	Unit 1	3	5822	1179
5	Unit 2	2	11850	168
5	Sat. Dykelet	1	6008	--
6	Unit 1	5	6341	1928
7	Granitic Hostrock	4	2578	1200
7	Unit 1	14	8451	5017
7	Unit 2	19	11226	1767
7	Chill. Margin	1	31201	--
8	Unit 1	5	7665	1937
9	Sat. Dykelet	2	24236	1640
10	Intermed. Volc. Hostrock	8	17114	5434
10	Unit 1	11	9009	4646
10	Unit 2	9	6826	1570
11	Unit 1	2	6987	624
11	Unit 2	2	6702	1643
12	Unit 1	4	12015	2201
13	Unit 1	4	10403	702
13	Sat. Dykelet	1	16880	--
14	Unit 1	13	9945	2159
14	Unit 2	8	5980	5015
14	Chill. Margin	4	11223	663
14	Sat. Dykelet	5	11146	1525
15	Unit 1	7	10185	1625
16	Unit 1	6	11178	1811

Table 10.2: Volume Susceptibility (Units are 10^{-6} SI)

Traverse	Group	N	mean value	standard deviation
2	Unit 1 ¹	5	19395	1887
2	Sat. Dykelet	3	52766	8899
3	Unit 1 ²	7	17106	4391
4	Unit 1	6	20006	4187
4	Dykelet + Sat. Dykelet	4	44512	18828
5	Sat. Dykelet	1	18816	
7	Unit 1	6	19440	10288
7	Unit 2	11	34253	7662
7'	Unit 2	5	19382	2679
9	Chill. Margin	5	19501	6342
9	Unit 2	5	34243	1556
10	Unit 1	4	22565	3338
10	Unit 2	9	21028	2777
11	Unit 2	5	11462	8672
12	Unit 1	5	35607	8200
14	Unit 1	3	32788	11675
14	Chill. Margin	1	37964	
14	Unit 2	6	15711	17262
14	Sat. Dykelet	6	35237	6224
15	Unit 1	4	27220	2056
16	Unit 1	6	35352	2075

¹samples RE842810 and RE842811 not included in average.

²samples RE842501 and RE842510 not included in average.

Mass Susceptibility

Fig. 10.3: Variation in average mass susceptibility along the GAD. Data given in Table 10.1. Mass susceptibility given in units of 10^{-6} SI. Error bars correspond to $\pm 2s$ uncertainty about each point value.

Volume Susceptibility

Fig. 10.4: Variation in average volume susceptibility along the GAD. Data is given in Table 10.2. Volume susceptibility given in units of 10^{-3} SI. Error bars correspond to $\pm 2\sigma$ uncertainty about each point value.

Fig. 10.5: Induced versus natural remanent magnetization. Both variables are in unit of $\log (A/m)$. The induced magnetization is calculated using an applied field of 60000 nT. Volume susceptibility data was used in calculating the induced moment.

Fig. 10.6: Elliptical region on equal area stereonet enclosing all possible magnetization (induced plus remanent) directions. Remanence directions are from Fig. 9.6. PEF is Present Earth's field direction at Timmins, Ontario: Dec = 349° , Inc. = 76° .

CHAPTER 11

MORPHOLOGY AND SPATIAL CHARACTERISTICS

11.1 INTRODUCTION

Aeromagnetic, ground magnetic, and outcrop data are used to produce a map of the Great Abitibi Dyke (GAD); this map can be found in the back pocket of this thesis and its method of preparation is detailed in Section A8.5. This map is used in surveying the regional variation in the trend and thickness of the dyke as well as in defining the pattern of en-echelon segments and fault offsets.

Dyke dip is modelled using aeromagnetic and ground magnetic profiles. The results are combined with dip estimates from field, paleomagnetic, and AMS measurements in order to characterize the variation in dyke dip along the GAD.

11.2 POSSIBLE BRANCHING AT THE NORTHEAST END

One of the most striking features on the map is the apparent branching of the dyke towards its northeast end. At the point of 'branching', outcrop data are unavailable and the aeromagnetic signature is ambiguous. Chemical and petrographic data are available from both 'branches' and are compared with similar data from well-studied parts of the GAD in order to assess whether one or both of these 'branches' belong to the GAD.

A chemical analysis from a sample at site 17 along the northern 'branch' is available from Hebert (1983) and is given in Table 11.1 (analysis 16). This analysis and an accompanying description of the

mineralogy, texture, and crystallization order match with the characteristics of unit 1 samples from the rest of the GAD. Key matches are in the high Al, Na, K, and P contents and in the apparent early crystallization of apatite (cf. Section 2.3.4). It is likely that the northern 'branch' belongs to the GAD.

The southern 'branch' consists of olivine diabase according to published maps (MERQ, 1981b) and has a similar chemical composition to the GAD (analysis DF148 in Table 11.1). On the other hand, chemical analyses in the vicinity of site 18 (analyses FA650525, FA650526, 14-83 and 15-A1 in Table 11.1) are dissimilar to the GAD. In particular, the contents of TiO_2 , K_2O , Ba, and the REEs are distinctly lower than those found in rocks from the GAD. These samples were collected in the vicinity of a Ni and Cu mineralized portion of the southern 'branch' and so they may not be representative of the southern 'branch'. Given conflicting chemistry it remains unresolved as to whether the southern 'branch' belongs to the GAD.

11.3 REGIONAL DISTRIBUTION

The distance from the southwestern end of the GAD to the point of 'branching' (near long. $75^{\circ}45'\text{W}$) is 590 km. The total length of the GAD including the northern 'branch' is more than 700 km. The distance over which the dyke was sampled for this thesis (between traverses 1 and 16) is 560 km.

The trend of the GAD averages about 70° , but in detail it has the following trends as averaged over ~100 km intervals starting from the southwest end: 66° (between 0 and 125 km), 63° (between 125 and 250

km), 65° (between 250 and 375 km), 68° (between 375 and 495 km), 71° (between 495 and 575 km), 55° (between 610 and 705 km along the northern 'branch'), and 65° (along the southern 'branch').

11.4 EN-ECHELON SEGMENTS

The GAD is in fact not a continuous feature (see map). It is broken up into en-echelon segments and is also slightly offset along faults (Section 11.5). The former are considered to be primary features and are not fault offsets because of curved and tapered ends which frequently overlap with adjacent segments.

The GAD is divided into at least 17 en-echelon segments (Table 11.2). All segments have the same sense of offset, each being rotated clockwise from the general trend of the dyke. The most distinctive en-echelon offsets occur between longitudes $77^{\circ}00'$ and $78^{\circ}30'W$. Five segments, SF to SJ (Table 11.2), have large offsets and overlap distances which are typically greater than 1 km. (Offset and overlap distances are measured in the direction perpendicular to, and along the dyke trend, respectively). Throughout the rest of the GAD, the offsets and overlaps are smaller. The complex branching pattern between segments SP and SQ (longitudes $81^{\circ}00'$ to $81^{\circ}15'W$) may be interpreted as either en-echelon segments with large offset and overlap distances, or as branching of the dyke towards the southwest.

Although the GAD is not a continuous feature at the present level of exposure, several characteristics suggest that all parts must be interconnected at some depth. The chemical evolution of all parts of

the GAD can be genetically related by crystal fractionation from a common parental magma (Chapter 5) and furthermore, the overall distribution of the dyke defines a remarkably linear feature across the Abitibi belt (Fig. 1.1 and Section 11.3).

Anderson (1951) and Pollard (1987) showed that en-echelon segments in a dyke can result from a changing stress configuration with depth, such that at a deeper crustal level, en-echelon segments merge into one continuous dyke. Therefore, at a deeper exposure level, the GAD may be continuous with a trend of approximately 70° . The observed en-echelon segments probably denote magma emplacement into a shallow level stress regime, in which the principal maximum stress is rotated clockwise from the general dyke trend. The angle between the general trend and the trend of an en-echelon segment is termed the twist angle and is generally less than 10° in the case of the GAD.

The inclination angle of magma propagation is constrained near the ends of en-echelon segments where it should approximately equal the plunge of en-echelon segment ends (Pollard, 1987). The plunge of segment ends has not been investigated for the GAD. However, a study by Smith (1987) on the Spanish Peaks dyke swarm showed that the ends of en-echelon segments need not be vertical, but can plunge at intermediate to shallow dips.

The largest en-echelon offsets are in the mid-length region of the GAD and are essentially absent towards the ends of the dyke. If en-echelon offsets are more prominent and numerous upwards through a

dyke (Pollard, 1987), then the simplest interpretation is that the GAD has shallowest level of exposure in its mid-length region. This variation in exposure level can be attributed to regional block tilting of a few degrees (Section 12.3).

11.5 POST-INTRUSIVE FAULTING AND FOLDING

The GAD has been cut by faults most of which have left lateral offsets generally of magnitude no larger than 1.5 km. The dyke crosses nearly the entire length of the Abitibi belt and along this entire distance, the cumulative offset due to later faults is small (<10 km) and is concentrated towards the southwest end of the dyke. This implies that since 1140 Ma (the age of the GAD), there has been insignificant movement along major north-south faults in the Abitibi belt, except possibly towards the southwest end in the vicinity of the Kapuskasing Structural Zone (KSZ).

Near longitude $80^{\circ}30'W$, the dyke abruptly changes to an E-W trend and follows the Destor-Porcupine fault, a major Archean transcurrent fault (OGS-MERQ, 1974), for a distance of about 3.5 km. The available mapping shows no deformation of the dyke within the fault. Clearly, the dyke fracture (and magma) took advantage of the weakened crust created by the Destor-Porcupine fault.

There are numerous undulations in the trend of the dyke with a wavelength of 1 to 4 km. From detailed mapping in the Beatty and Munro townships (approx. long. $80^{\circ}15'W$), Johnstone (1987) postulated that these undulations result from late Proterozoic folding about southwest plunging axes. This episode of deformation may be recognized

in the palcomagnetic data (Section 9.6).

11.6 VARIATION IN DYKE-WIDTH

The variation in dyke-width along strike is only roughly known (Fig. 11.1; Table 11.3; and map in back pocket). Outcrop data indicate that the dyke is widest (ca. 200-250 m) at its mid-length. It tapers to ca. 80-100 m towards both ends. The data also suggest that the GAD tapers more gradually towards its southwest end. Overall the GAD has an elongate elliptical shape, which is slightly asymmetric, being wider towards the southwest end.

The overall elliptical shape of the GAD suggests emplacement into a homogeneous and isotropic host rock terrane which has been subjected to uniform internal pressures and uniform regional stresses (Pollard and Muller, 1976).

The slight longitudinal asymmetry in dyke-width can be explained by either longitudinal gradients in host rock stiffness, regional stresses, magma pressure, or a changing geometry with depth of exposure (Pollard and Muller, 1976). Of these possibilities only the first can be eliminated in the case of the GAD, because host rock type (and presumably) host rock properties do vary, but not progressively, across the Abitibi belt (OGS-MERQ, 1974). The asymmetry could be explained by greater magma pressure or greater dyke opening stresses towards the southwest as a consequence of proximity to the Keweenaw rift system. Alternatively, the variation in dyke width may be due to an oblique surface exposure through the GAD (see Section 12.3).

Regarding this latter possibility, Weertman (1971) suggests that in vertical cross-section, a magma-filled crack has the shape of an asymmetric ellipse ('tear drop') with the wider end upwards. Various authors (Ernst and Halls, 1983; Halls et al., 1985; Fahrig, 1987) have suggested that as a consequence dyke thickness will vary with depth of exposure and on average will thin with depth. With reference to a single dyke such as the GAD, this effect may be difficult to distinguish from the tendency for the dyke to thin towards its ends, particularly if exposure depth is not well constrained. Also, according to Weertman's model a dyke exposed near its top, will thicken instead of thinning with increasing depth of exposure.

11.7 MAGNETIC MODELLING

11.7.1 Previous Studies

Variation in dyke-dip along the length of the GAD can be assessed through modelling of ground and aeromagnetic data. Preliminary work on this has been done by Schwarz et al. (1987). They studied the dyke in two locations, near traverses 7 and 12 of the present study, and combined all profiles from both areas into a single profile from which a regional gradient was removed before modelling. Their study concluded that the GAD in both areas extends to a depth of at least 10 km and has a steep northerly dip.

11.7.2 Ground Magnetic Profiles

Ground magnetic profiles were collected using a portable proton magnetometer (Appendix A8.6). Data from 12 profiles are given in Fig.

11.2; all are from the vicinity of the traverses shown in Fig. 1.1.

Profiles B and C (both from traverse 15) are compared. The profile lacking any surface outcrops (profile B) has a much smoother anomaly pattern than does the profile across an outcrop rich area (C). The high frequency magnetic signal has been attenuated in profile B by the presence of intervening surficial deposits.

In profiles B, C, D, E, J, and probably F, the anomaly pattern drops off at the dyke contact. However, in profiles G, H, I, K, and L the anomaly remains at a high level out into the host rock for approximately a half to a full dyke width. In these latter cases the host rock is composed of intermediate to mafic volcanics which have been enriched in magnetite by contact metamorphism associated with dyke emplacement (e.g. Schwarz et al., 1987) (cf. Section 10.4).

11.7.3 Aeromagnetic Profiles

Data from 44 aeromagnetic profiles (Fig. 11.3) have been extracted from the 1:20,000 maps used in producing the map in the back pocket (see Section A8.5). In all cases, the data were selected from along flight line paths which were scaled so as to represent a profile perpendicular to the dyke trend. Profiles were selected where the background host rock magnetic intensity had low amplitude and only broad wavelength variation.

In Fig. 11.3 the aeromagnetic profiles are arranged in order from northeast to southwest along the GAD. A systematic variation in anomaly amplitude is observed along the dyke. The anomaly amplitude is small (200 to 300 nT) at both northeast and southwest ends of the dyke

but increases towards the mid-length of the dyke (with values typically between 500 and 800 nT) and reaches >1100 nT at profiles V, W and X. These three profiles, V, W and X, lie along a single enechelon segment located between $79^{\circ}00'$ and $79^{\circ}15'W$.

Anomaly amplitude in dykes is controlled by magnetization intensity, depth of burial, depth extent and dyke width. These are considered in turn. Bulk susceptibility data and an analysis of Q values (Section 10.5) suggest that the magnetization is relatively uniform throughout most of the dyke. The depth of burial must be essentially zero, according to geological maps. Also, most of the dyke can be considered to have 'infinite' depth extent; in practical terms, this means a depth extent greater than a few kilometres (See Table A12.1). Therefore, the variation in anomaly amplitude in Fig. 11.3 is mainly controlled by dyke width. This result implies that the dyke (plus 'baked' host rock) tapers in width towards northeast and southwest ends and is thickest at its mid-length section (cf. Section 11.6).

11.8 ESTIMATE OF DIP VARIATION ALONG STRIKE

11.8.1 Modelling Procedures

The aeromagnetic and ground magnetic profiles were modelled to quantitatively determine the dyke dip and its variation along strike. No attempt was made to model the thickness or the susceptibility contrast between dyke and host rock, because it would be impossible at most traverses to distinguish the contribution of the dyke from that

of adjacent baked (and magnetized) host rock (Section 11.7.2).

The aeromagnetic profiles were modelled to determine dip in two ways: two profiles were modelled interactively using the computer program MAGRAV2 (Broome, 1986) and the remainder were modelled using type curves (Fig. A13.1). The type curves were generated using MAGRAV2.

Profiles L and AD were modelled interactively by fitting each anomaly by a simple tabular dyke (Fig. 11.4). Profile L is modelled with a north dipping dyke and AD is modelled with a nearly vertical dyke (Fig. 11.3). The magnetization direction used in modelling was that of the present Earth's field (PEF) (see Section 10.4 and Section A12.1).

A set of type curves have also been derived (Fig. A13.1) using MAGRAV2. The type curves are derived from tabular bodies with parallel sides and dips ranging from $+50^{\circ}\text{N}$ to $+50^{\circ}\text{S}$ in intervals of 10° , surface widths of both 400 metres and 100 metres, a depth extent of 5 km, 'flight elevation' of 0.12 km, body magnetization of 1.5 A/m, a magnetization direction of the present earth's field (PEF) and a dyke strike of 70° . These parameters were chosen to be representative of the GAD (Fig. 10.5, Sections 10.6 and 11.7.2, Section A12.1 and Table A12.1).

Type curves were superimposed on each anomaly to identify the best fitting type curve. It was most critical to fit the shape of the flanks of the anomaly, since dyke-dip was the feature of interest. Sources of uncertainty in the modelling are mainly in the

magnetization direction and are approximately 10^0 (Section 10.6).

In modelling, no regional gradient was removed because: (1) quiet areas were picked for analysis, so any regional gradient should be minor, (2) the length of the profile is short and any reasonable regional gradient would have a small effect over a few kilometres, and (3) the change in the magnitude of the the Earth's field is small over a distance of a few kilometres (Schwarz et al., 1987). In modelling their data from the GAD, Schwarz et al. (1987) removed a small regional gradient (approximately 20 nT over 6 km) prior to modelling. Removal of this small gradient would have essentially no effect on the models in Fig. 11.3. Some profiles, i.e. those labelled G, H, M, S, AB, AC, and AL indicate the presence of a secondary anomaly superimposed on the primary field of the dyke. An analysis of the causative bodies of these secondary anomalies would require separation of the various superimposed gradients, which is outside the scope of this study.

11.8.2 Results

The estimates of the dip obtained from ground and aeromagnetic modelling are compared with estimates from other sources, that is field observations, paleomagnetism and AMS. All the estimates are compiled in Table 11.4 and displayed in Fig. 11.5. Locations are keyed to the map in the back pocket. Note that the dips determined from aeromagnetic modelling are generally in accord with results from other techniques. This agreement between techniques improves one's confidence in all the estimates of dyke dip.

Along both 'branches' at the northeast end of the dyke, the dyke dips steeply to the north. Given a close proximity to the Grenville Front, the non-vertical inclination along these segments probably reflects Grenvillian thrusting onto the Superior Province (Davidson, 1984; Green et al., 1988) and downwards flexure of the Superior Craton. The dyke is nearly vertical between profiles E and K. Dips are irregular between profile L, (traverse 15) and profile M. Profiles O, P and Q are all from a single en-echelon segment and have approximately 70° northward dips which differ from the dip in adjacent en-echelon segments. Profiles R and S, both from another en-echelon segment, have dips of 70° to 80° S. Profiles T and U have 70° to 80° N dips. Dips from the echelon segment containing profiles V, W and X have 70° S to 90° dips. At traverse 14 and profile Z the dyke has 70° to 80° S dips. Dips along the rest of the dyke are typically to the north. Exceptions are between profile AE and traverse 11, at traverse 7 and perhaps at profiles AL and AM (all 70° to 80° S).

In summary, the dyke varies in dip between 70° N and 70° S and on average it dips vertically. Some segments have distinctly non-vertical dips. Both 'branches' at the north end of the dyke dip northward between 60° and 80° N, and, at the southwest end, 10 of 12 measured dips are to the north.

11.9 CONCLUSIONS

The principal results of this chapter are:

- 1) Towards its northeast end the GAD appears to split into two

branches. The northern 'branch' is shown to belong to the GAD while the relationship of the southern 'branch' is uncertain.

2) The total length of the GAD is at least 700 km assuming that the northern 'branch' is a continuation of the GAD.

3) There are at least 17 en-echelon offsets and all are rotated clockwise from the general trend of the dyke.

4) Crosscutting faults cause only small offsets, most being left-lateral.

5) Dyke width is maximum (250 m) at mid-length and tapers towards both ends (<80 m). The overall surface shape appears to be of an asymmetric ellipse (wider towards the southwest end).

6) Volcanic host rock, adjacent to the dyke, has been enriched in magnetite and has an enhanced magnetization relative to the host rock further away from the dyke.

7) The dip of the GAD varies between 70°N and 70°S , but on average is vertical. At the northeast end (and also possibly at the southwest end) the dyke dips are steeply northward (70° to 80°N).

Table 11.1: Chemical analyses

	Fresh olivine gabbro (N. Branch) SITE 17	Fresh olivine diabase (S. Branch) EXACT LOC. UNSPECIFIED	Vicinity of Site 18 Diabase with sulphide mineralization (S. Branch) VICINITY OF SITE 18			
	Analysis 16 ¹	DF148 ³	FA650525 ²	FA650526 ²	14-B3 ⁴	15-A1 ⁴
SiO ₂	48.00	45.20	49.20	47.90		
TiO ₂	3.08	2.80	0.64	1.84		
Al ₂ O ₃	16.40	15.70	16.60	13.50		
Fe ₂ O ₃ ^T		15.2				
Fe ₂ O ₃	2.85		1.30	3.40		
FeO	9.86		7.10	12.60		
MgO	4.54	5.30	9.26	6.49		
CaO	8.51	9.51	10.50	10.00		
Na ₂ O	3.93	2.51	2.00	2.40		
K ₂ O	1.38	1.43	0.54	0.33		
P ₂ O ₅	0.64	0.39	0.08	0.10		
MnO	0.17	0.20	0.15	0.24		
L.O.I.	0.87	2.24	2.30	1.30		
TOTAL	100.23	100.48	99.67	100.10		
Li					136	3
Zr	50		90			
Nb	16					
Cu	22				59	392
Zn	140				70	469
Ba	80		20		352	162
Sr	330		130			
V					228	212
Ni	160		60		124	78
Cr					202	146
Co					48	58
Mo	< 0.3				< 4	< 4
Sc					35	32
U	2				< 0.2	0.5
Th	< 5					
Pb	< 0.3				< 12	< 12
La					5	11
Ce					6	17
Pr					< 10	< 10
Nd					< 25	< 25
Sm					< 2	< 2
Eu					1	2
Dy					< 1	3
Ym					< 2	< 2

¹Hebert, Y. (1983)²Fahrig, M. (pers. comm., 1988)³Dube, C. (pers. comm., 1988)⁴Barnes, S.-J. (pers. comm., 1988)

Table 11.2: En Echelon Segments and Offsets

Segments

Label	Location	Segment Trend (distance over which meas. taken)	Twist Angle (segment trend minus regional trend)	Segment Length
SA	crosses 75°00'	60° (12.0 km; meas. from west end)	5°	—
SB	nearby to the east of 75°15'W	67° (4.2 km)	13°	4.2 km
SC	east of & crosses 75°15'W	53° (6.4 km)	-1°	6.4 km
SD	west of & crosses 75°15'W	59° (10.1 km)	5°	10.0 km
SE	crosses 75°30'W	61° (12.2 km; meas. from east end)	6°	—
SE	crosses 77°00'W	69° (12.9 km; meas. from west end)	1°	—
SF	crosses 77°15'W	75° (10.9 km)	8°	10.9 km
SG	between 77°15' & 77°30'W	67° (9.6 km)	0°	9.6 km
SH	crosses 77°30'W & 49°30'N	80° (9.3 km)	13°	15.4 km
SI	crosses 77°45'W	69° (22.5 km)	2°	25.7 km
SJ	crosses 78°00'W	65° (12.9 km)	-2°	38.0 km
SK	crosses 78°15' & 78°30'W	70° (22.1 km)	3°	22.1 km
SL	crosses 78°45'W	65° (30.2 km)	0°	30.2 km
SM	crosses 79°00' & 79°15'W	61° (30.9 km)	-4°	30.9 km
SN	nearby to the west of 79°15'W	67° (3.2 km)	2°	3.2 km

(Continued on next page)

Table 11.2

SO	west of segment SN	73° (7.7 km; meas. from east end)	8°	—
SO	crosses 48°30'N	54° (13.5 km; meas. from west end)	-9°	—
SP	crosses 80°45' & 81°00'W	64° (23.2 km; meas. from east end)	1°	4! 5 km
SQ	overlaps segment SP & crosses 81°15'W	58° (19.3 km; meas. from east end)	-5°	—

Offsets

Location	Offset Distance	Overlap Distance
SA to SB	0.5 km	0.0 km
SB to SC	0.8 km	0.5 km
SC to SD	0.6 km	0.4 km
SD to SE	0.5 km	0.5 km
SE to SF	0.6 km	1.0 km
SF to SG	1.1 km	2.1 km
SG to SH	1.0 km	0.6 km
SH to SI	1.6 km	3.9 km
SI to SJ	2.7 km	3.2 km
SJ to SK	1.5 km	1.8 km
SK to SL	0.1 km	0.1 km
SL to SM	0.2 km	0.1 km
SM to SN	0.5 km	0.4 km
SN to SO	0.5 km	0.4 km
SO to SP	0.8 km	2.6 km
SP to SQ	1.7 km	12.9 km

All offsets in same sense; all segments are clockwise rotated from the general trend.

Offset at 'SP to SQ' may alternatively be interpreted as a westward directed branching of the dyke.

Average dyke trend is: 55° for segments SA - SD & SE (east end), 68° for segments SE (west end) & SF - SK, 65° for segments SL - SN & SO (east end), and 63° for segments SO (west end), and SP & SQ (east end).

Fig. 11.1: Variation in dyke-width along the Great Abitibi Dyke. The dashed line at 160 km connects measurements on different overlapping en-echelon segments. The dashed line between 590 and 610 km marks the point of convergence of two 'branches' of the GAD. Data from > 600 km is only from the southern 'branch'. Open symbols represent minimum estimates.

Table 11.3: Width of the GAD from Outcrop Data

Along-Dyke Position (kilometres)	Dyke Width (metres)	Map Scale for Source Data	Reference
0	Southwest End of the Dyke		
32	90	--	traverse 2
57	150	--	traverse 3
62	80	1:63360	Harding (1937) map #46A
64	140	--	traverse 4
80	110	--	traverse 5
88	110	1:31680	Milne (1972) map #2231
118	210	--	traverse 7
139	230	1:50000	Pyke (1982) map #2245
155	90	1:50000	Pyke (1982) map #2245
164	90	1:50000	Pyke (1982) map #2245
165	100	1:31680	Leahy (1971) map #2222
162	230	1:31680	Leahy (1971) map #2222
163	220	--	traverse 8
166	240	1:31680	Leahy (1971) map #2222
172	230	1:31680	Leahy (1971) map #2222
195	190	--	traverse 9
203	190	--	traverse 10
205	140	--	traverse 10'
207	160	--	traverse 11
222	260	1:16050	Johnstone (1987)
227	250	1:16050	Johnstone (1987)
293	190	--	traverse 12
301	220	--	traverse 14
440	>100	1:20000	MERQ (1981) DP657
467	>100	1:20000	MERQ (1981) DP657
486	150	--	traverse 15
588	90	--	traverse 16
Southern Branch			
610	80	1:20000	MERQ (1981) DP829
612	110	1:20000	MERQ (1981) DP829
616	60	1:20000	MERQ (1981) DP829
618	40	1:20000	MERQ (1981) DP829
625	80	1:20000	MERQ (1981) DP829

Fig. 11.2: Ground magnetic profiles. Anomaly height is in units of nT. Large dot pattern beneath the anomaly locates unit 2. Smaller dot pattern locates unit 1. Outcrop data is presented in a horizontal strip located immediately above the horizontal distance scale. Full-height vertical lines locate outcrops of the GAD while half-height vertical lines locate outcrops of host rock. Where outcrop was unavailable, unit 1 and 2 regions were located by extrapolation from areas having outcrop control.

Fig. 11.2

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Fig. 11.2

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Fig. 11.2

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Fig. 11.2

Fig. 11.3: Aeromagnetic profiles (solid lines) with 'best fit' type curves (dotted lines) and modelled dip angle. Each graph is labelled with a letter-angle combination which denotes the profile (see map in back pocket) and gives the local dyke trend. For instance C (44°) refers to profile C and local dyke trend of 44°. Profiles were collected along flight lines (generally trending N-S) and then 'compressed' to so as to represent a profile perpendicular to the dyke trend. Type curves are taken from Appendix A12.1.

Fig. 11.3

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Fig. 11.3

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Fig. 11.3

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Fig. 11.3

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Fig. 11.3

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Fig. 11.3

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Fig. 11.3

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Fig. 11.3

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Fig. 11.3

Fig. 11.4: Two aeromagnetic profiles modelled interactively using the computer program MAGRAV2 (Broome, 1986). M is the magnetization of the dyke; the host rock is assumed to have no magnetic moment. Vertical and horizontal distance scales are the same. In both cases, the dyke is modelled to extend to at least 3 km depth. Modelling of the GAD is very insensitive to changes in depth-extent greater than this depth and therefore no upper limit on the depth-extent can be obtained by modelling. (See also Table A12.1.)

Fig. 11.4

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Fig. 11.4

Table 11.4 Summary of Dyke-Dip Information. Data Sources are: Modelling of Aeromagnetic and Ground Magnetic Profiles, Field Observations, Anisotropy of Magnetic Susceptibility (AMS) Measurements and Paleomagnetic Measurements

LOCATION	AERO-MAGNETIC	GROUND MAGNETIC	FIELD OBSERV.	AMS	PALEO-MAGNETISM	COMMENTS
A*	70°N					South Branch
B*	80°N					South Branch
C*	50°-60°N					South Branch
A	80°N					North Branch
B	60°-70°N					North Branch
C	90°N					North Branch
D	80°S					
16			80°-85°N	80°N		
E	80°S					
F	80°S-90°					
G	80°S-90°?					
H	70°-80°S					
I	90°					
J	80°N-90°					
K	80°S-90°					
L	70°N					
15		90°		90°		
M	80°N					Segment End
N	80°N-90°					Segment End
O	60°-70°N					Segment End
P	60°-70°N					
Q	70°N?					
R	80°S					Segment End
S	70°S					
T	70°-80°N					Segment End
U	80°N					Segment End
V	80°S					Segment End
W	70°S					
X	90°					
Y	80°N					Segment End
14		70°-80°S		65°S		
Z	80°S					
13						
12		90°		80°S		

(Continued on next page)

Table 11.4

LOCATION	AERO-MAGNETIC	GROUND MAGNETIC	FIELD OBSERV.	AMS	PALEO-MAGNETISM	COMMENTS
AA	80°N					
AB	60°N					
AC	70°-80°N					
AD	90°					
AE	70°S					
11		70°-80°S			85°SE? ¹	Crosses Fault
10'						
10		80°N-90°	90°	90°		
AF	90°					
9						
<hr/>						Segment End
AG	80°N					
<hr/>						Segment End
7"						
7		80°S	70°-80°S	?		
6						
5					80°N	
4			75°N		80°N	
3		70°N	70°N	?	80°N	
AH	70°-80°N					
AI	70°N					
AJ	80°N					
2		90°	80°-85°N	?	90°? ²	
1						
AK	80°N					
AL	70°-80°S?					
AM	80°S					
AN	80°-90°N					
AO	70°N					

¹The simplest tectonic correction of the paleomagnetic data from traverse 11 is about a horizontal axis with NE trend. Since the dyke has a trend of 20° NE at this traverse, then approximately 5° of the paleomagnetic correction applies to the dyke dip.

²The tectonic correction of the paleomagnetic data from traverse 2 is about a horizontal N-S axis, i.e. perpendicular to the dyke trend. Therefore, no tectonic correction of the dip is required.

Fig. 11.5: Variation in dyke-dip along the GAD. The data are tabulated in Table 11.4, + labels data from the southern 'branch' of the GAD. Vertical lines separate echelon segments. Error bar indicates the 2s uncertainty based on the uncertainty in magnetization direction (Section 10.6).

CHAPTER 12

EMPLACEMENT AND TECTONIC HISTORY

12.1 INTRODUCTION

The petrological and geophysical data presented in previous chapters can be used to constrain possible models for the emplacement history of the Great Abitibi Dyke (GAD). The relationship between the GAD and other regional tectonic elements is evaluated.

12.2 MAGMA FLOW DIRECTION RECORDED IN UNIT 1 ROCKS

AMS data from unit 1 are thought to indicate magma emplacement along a sub-horizontal trajectory (Section 8.5.3). A similar trajectory of magma emplacement has been determined for other dykes. In particular, textural, AMS, and seismic studies of dykes from Hawaii (e.g. Knight and Walker, 1988), Iceland (Sigurdsson, 1987), Spanish Peaks, Colorado (Smith, 1987), and Ramon, Israel (Baer and Reches, 1987) have demonstrated, that while the flow direction of dykes can be highly variable, it is dominantly sub-horizontal.

If the unit 1 magma was emplaced along a sub-horizontal trajectory then it must have come either from the northeast or southwest. The chemistry of unit 1 rocks exhibits a slightly more evolved character towards the northeast end of the GAD (Section 6.2.5), which may be attributed to side-wall fractionation (Irving, 1980) of unit 1 magma moving along a sub-horizontal trajectory towards the northeast. This would imply a magma source to the southwest of the dyke.

To the southwest of the GAD, the Lake Superior basin hosts a thick accumulation of Keweenawan mafic volcanics and dykes having ages ranging between 1110 to 1085 Ma (Table 12.1). These Keweenawan rocks are about 30 Ma younger in age than the GAD, but are probably related to the same magmatic event as the GAD (Section 12.5.1). In contrast, at the northeast end of the GAD, the Grenville Province, contains few mafic igneous rocks of this age (Easton, 1986).

The above evidence is consistent with a magma source for the GAD within the Keweenawan rift at the southwest end of the dyke.

12.3 REGIONAL VARIATION IN THE DEPTH OF EXPOSURE

The GAD shows regional variation in the abundance of en-echelon segments and unit 2 chemistry which may be related to variation in the depth of exposure as follows:

En-echelon segmentation of the GAD is most prominent in the mid-length region of the dyke between longitudes 77°00' and 78°30'W and is absent from the ends of the dyke (Section 11.4). En-echelon segmentation is expected to be more pronounced at shallower exposure levels and on this basis the GAD would have the shallowest level of exposure midway along its length.

In unit 2 rocks, the ratio of plagioclase to mafic minerals decreases from the southwest end of the dyke towards the mid-length region (Section 6.3). This along-dyke variation can be explained by an oblique exposure through a vertically-zoned dyke (Fig. 6.8B), the more dense mineral phases being concentrated at a deeper exposure level towards the southwest (Ernst et al., 1987).

While the GAD remains unmetamorphosed along its entire length, the regional variation in the host rock metamorphic grade is consistent with the shallowest level of exposure being located at mid-length along the GAD. Host rocks from the mid-length region of the dyke do not exceed greenschist facies (Fraser et al., 1978; Ernst and Halls, 1983), while towards both the southwest and northeast ends of the dyke, the host rock metamorphic grade reaches lower amphibolite facies. The coincidence between least metamorphosed portions of the Archean rocks of the Abitibi belt and the proposed shallowest parts of the GAD suggests that crustal flexure did not occur until after 1140 Ma, i.e. after emplacement of the GAD and perhaps in association with the Grenville orogeny.

The postulated variation in exposure level is gradual. Even if the cumulative change in depth was 10 km, this change in depth occurs over several hundred kilometres, and therefore, the average angle of tilting would only be a few degrees. This magnitude of tilting is too small to have affected the chemical and AMS data from unit 1 rocks, data which had been used to support a model of sub-horizontal magma flow (Section 12.2).

12.4 GENESIS OF UNIT 2 MAGMA

Although unit 1 and 2 rocks were derived from the same parental magma, the crystallization history of each unit is quite different. Unit 1 behaved as a closed system, such that fractional losses from the near margin rocks of unit 1 are balanced by fractional gains (i.e. cumulates) within the interior of unit 1.

In contrast, the derivation of unit 2 rocks from the parental magma requires the loss of approximately half the magma volume by crystallization of plagioclase, olivine, titanomagnetite and ilmenite. The fractionate is not observed anywhere along the present exposure level of the GAD and must have been efficiently removed.

A mechanism for generating unit 2 magma within the dyke conduit is illustrated in Fig. 12.2. Single crystals or crystal-laden plumes could 'rain' down the dyke-conduit to depths below the present exposure level (Shirley, 1987), leaving behind an evolved 'saddle' (Fahrig, 1985) which corresponds to the magma which crystallized as unit 2.

Alternatively, unit 2 may have been derived in an external magma chamber from which it was then injected into the GAD. Injection of unit 2 can explain various features such as (1) the sharp change in chemistry at the boundary between units 1 and 2 (Figs. 3.4 and 3.5), (2) the gap in cooling times between units 1 and 2 revealed by the paleomagnetic data, and (3) the evidence that the parts of the dyke containing unit 2 rocks are typically wider than parts which contain only unit 1 rocks (e.g. Figs. 1.2, 6.1 and 11.1).

An external magma chamber could be located along, below, or above the present exposure level of the dyke, and could either be distributed along the entire length of unit 2 (i.e. between traverses 5 and 14) or be more localized. Fig. 12.3 summarizes the possible locations of external chambers.

The synformal distribution of feldspar foliation (Section 2.2.3)

requires some downwards movement of unit 2 magma, either downwards magma injection from an overlying chamber, #4 in Fig. 12.3 and Fig. 12.4, or simply a minor late-stage drop in magma level, compatible with #s 1, 2 and 3 in Fig. 12.3.

12.5 REGIONAL TECTONIC MODEL

12.5.1 Relationship with the Keweenawan Rift

At approximately 1100 Ma the North American craton was affected by an event that produced the Keweenawan Rift (also called the Midcontinent Rift). The rocks of the Keweenawan Rift extend northeast from Kansas into the Lake Superior basin and then east and southwards through Michigan and perhaps into northeastern Ohio (e.g. Halls, 1978; Van Schmus and Hinze, 1985; Green et al., 1987).

Some dykes of the Abitibi swarm (particularly, the Kipling and the GAD) fan over a narrow arc away from the Superior basin (Fig. 12.1). This geometry suggests that the dykes mark a "failed arm" associated with Keweenawan rifting (Burke and Dewey, 1973; Condie, et al., 1987; Fahrig, 1987).

The GAD and presumably the rest of the Abitibi swarm at 1140 Ma predate all other Keweenawan igneous activity in the Lake Superior region which have ages between 1110 and 1085 Ma (Table 12.1). The GAD has normal paleomagnetic polarity, and must belong to the older normal polarity epoch (Table 12.1). No Keweenawan lavas are known from this earlier normal time period although earlier studies had incorrectly interpreted a lower normal polarity direction from the Powder Mill Group (Palmer and Halls, 1986). Recently, two lamprophyre dykes from

near the town of Wawa (near Lake Superior) have yielded a high-precision U-Pb age identical to that of the GAD (L. Heaman, pers. comm., 1988) suggesting that emplacement of the GAD and the lamprophyre dykes may mark a specific igneous event which may be the earliest manifestation of the Keweenawan rift event.

The GAD has many chemical characteristics in common with Keweenawan basaltic rocks (BVSP, 1981). Both tend to be Al-rich, have positive Eu-anomalies and light REE-enriched patterns, and show an iron-enrichment trend. A key difference between the GAD and Keweenawan rocks is that Keweenawan dykes and lavas are tholeiitic (both olivine and quartz tholeiites) (Green et al., 1987) while the GAD and other dykes of the Abitibi swarm (Card et al., 1981) typically show transitional to alkaline characteristics. No modelling has been done to relate the chemistry of the GAD and Keweenawan rocks to a common parental magma or a common mantle source.

12.5.2 Relationship to the Grenville Orogen

The age of the GAD (1140 Ma; Krogh et al., 1987) roughly coincides with a compressive phase of the Grenvillian Orogeny (e.g. Gibb et al., 1983; Easton, 1986; Windley, 1986) suggesting a tectonic relationship between the two.

At the northeastern end of the GAD, dykes of the Abitibi swarm fan out from the Mistassini Bulge, which is a bend in Grenville Front (separating the Superior and Grenville Provinces). The Grenville Front, northeast of the Mistassini Bulge, is associated with a

prominent negative gravity anomaly. The gravity anomaly may be due to crustal thickening during compression, and it is possible to construct the stress trajectories within the Superior Province resulting from boundary loads associated with the Grenvillian Orogeny (Fig. 12.2). The strike of the GAD and related dykes east of the KSZ is everywhere normal to the direction of minimum compression (Ranalli and Ernst, 1986). This would suggest that the GAD and related dykes were emplaced in response to a stress field associated with Grenvillian orogenesis.

Given the relationship between the GAD and Keweenaw rift discussed in Section 12.5.1 it is also interesting that Grenvillian compression has been proposed as a cause of Keweenaw rifting. Donaldson and Irving (1972) proposed that oblique collision along a strike-slip fault became locked at a bend in a Grenville suture, and rifted open the brittle craton in the vicinity of Lake Superior. Alternatively, Gordon and Hempton (1986) proposed that the Keweenaw rift comprises a series of pull-apart basins which developed between strike-slip faults activated during the Grenvillian orogeny.

12.5.3 Relationship to Kapuskasing Structural Zone

The Kapuskasing Structural Zone cuts across the Superior Province between Lake Superior and James Bay, and marks a break along which east-verging thrusting occurred at approximately 2100-1900 Ma (Percival and McGrath, 1986). Although the predominant movement along KSZ faults occurred around 2000 Ma, the southern KSZ appears to have also been the locus of activity coeval with intrusion of the GAD. K/Ar and $^{40}\text{Ar}/^{39}\text{Ar}$ ages of feldspars were partially reset between 1200 to

1000 Ma (Farrar and Archibald, 1985; Lopez-Martinez and York, 1986). Rocks of the KSZ have also been overprinted with a remanence direction dated at approximately 1100 Ma (Constanzo-Alvarez and Dunlop, 1988). These overprints may be due to the intrusion of alkalic complexes, the Nemegoscenda Lake, Borden Lake and particularly the Lackner Lake complexes, which have similar ages and paleomagnetic directions to the GAD (Bell and Blenkinsop, 1980; Dunlop et al., 1988; Symons, 1988).

The southern boundary of the KSZ is marked by a fault along which both strike-slip and vertical offset has occurred. The GAD is on line with this southern boundary fault but apparently thins out before reaching it. This colinearity of the trace of the GAD and the southern KSZ boundary fault suggests a relationship. Although no major offsets of the Abitibi Belt are observed across the GAD, there is some evidence, presented below, that the GAD was emplaced along a zone of pre-existing weakness which possibly developed at the time the KSZ boundary fault was active.

Near traverse 7, the Abitibi Belt underwent differential movement north and south of the GAD, marked by a change in the dip (Fig. 12.5) of an older (2454 ± 2 Ma; Heaman, 1988) crosscutting dyke swarm, the Hearst-Matachewan swarm (Ernst and Halls, 1984).

In the region between traverses 10-14, dykes of the Preissac swarm are refracted into the trace of the GAD (see maps in Card et al. 1981; Fahrig and West, 1986; Goodwin et al. 1972). The Preissac dykes have an overall northeast trend, but in the vicinity of the GAD, they have an east northeast trend which is approximately parallel to the

GAD. The Preissac dykes have an age of approximately 2100 Ma (Fahrig and West, 1986), and hence are approximately coeval with the main thrusting episode along the KSZ (Percival and McGrath, 1986).

The above observations from the vicinity of traverses 7 and 10 - 14 suggest that the emplacement of the GAD-magma at 1140 Ma may have taken advantage of a pre-existing zone of weakness colinear with the southern boundary fault of the KSZ, and that this zone may be an extension of the KSZ fault. The host rock of the GAD should retain some textural evidence of the proposed fracturing. Although none was observed in this study, few observations were made of the host rocks.

12.5.4 Models For Emplacement of the GAD

Two models for the relationship between the GAD, Keweenawan and Grenvillian events are presented below:

Model 1: Grenville collision. In this model, emplacement at 1140 Ma of the GAD and other Abitibi dykes east of the KSZ was caused by compression at the Grenville Front northeast of the Mistassini bulge (MB in Fig. 12.1). The two largest of these Abitibi dykes, namely, the GAD and a parallel-trending companion about 10 km to the north, were emplaced along the zone of weakness postulated to have been developed a billion years earlier during KSZ-thrusting.

Between 1110 and 1085 Ma (corresponding to the age-range of Keweenawan rocks), the locus of maximum compression had moved southwards from the Mistassini bulge and was concentrated near present Lake Huron where the Grenville Front changes trend from ENE-WSW to N-S

(Fig. 12.1). This new stress configuration caused formation of Keweenaw pull-apart basins throughout the Great Lakes region and elsewhere in the continental interior (Gordon and Hempton, 1986). The Kipling dyke and other dykes of the Abitibi swarm west of the KSZ trend similarly to the western arm of the Keweenaw rift, and could also have had origin at this time as incipient pull apart basins. This model would imply that the Abitibi dykes west and east of the KSZ differ in age by at least 20 Ma.

Model 2: Concurrent Grenville Compression and Keweenaw hot spot Activity. In this model, at 1140 Ma, upwelling asthenosphere began to impinge on the lithosphere in the Lake Superior region. The earliest effect of the upwelling was emplacement of the Abitibi dyke swarm both east and west of the KSZ. The location of the dykes east of the KSZ was also influenced by (1) Grenville compression localized northeast of the Mistassini bulge and (2) a pre-existing zone of weakness along the extension of the southern boundary zone of the KSZ. In this model the Abitibi dykes east and west of the KSZ would have the same age, i.e. 1140 Ma. The continued presence of the upwelling mantle hot spot would eventually result in the development (30 Ma later) of the two rift arms of the Keweenaw Rift System.

Discussion

Although Grenville stresses may have created potential fractures along which magma could move, melt generation is attributed to upwelling hot asthenosphere (White et al., 1987). Model number 2

postulates upwelling associated with the Keweenawan rift to generate the magma of the Abitibi swarm and simultaneous Grenville compression to help open fractures which gave the Abitibi dyke magma access into the crust. Model 2 is the interpretation preferred by the author.

Fig. 12.1: Regional tectonic features in the vicinity of the Great Abitibi Dyke. GF, Grenville Front, MB, Mistassini Bulge; GL Grenville Front Gravity Low; CG Chibougamau-Gatineau Lineament; AB, Abitibi; GAD, Great Abitibi Dyke; K, Kipling Dyke; KSZ, Kapuskasing Structural Zone; KR Keweenawan rift. Open circles denote carbonatite intrusive complexes near the southern end of the KSZ. Strike-slip faults are proposed master faults which controlled formation of Keweenawan pull-apart basins (Gordon and Hempton, 1987). Inset diagram shows stress trajectories in the Superior Craton arising from a distributed boundary load $P = p \cdot \Delta L$ acting on the segment ΔL of the Superior boundary northeast of the Mistassini Bulge and coincident with the location of the GL. Stippled pattern follows margins of bodies of water, i.e. the Great Lakes, Hudson Bay and the Gulf of St. Lawrence.

Table 12.1: High precision U-Pb ages and the magnetic polarity time scale for Keweenawan rocks

MAGNETIC POLARITY	PRECISE U-PB AGES (GIVEN IN MA)	
NORMAL	A	1086 PALMER AND DAVIS (1986)
	B	1097.6 ± 3.7
REVERSED	C	1107.5 $+4/-2$
	D	1108.8 $+4/-2$ } DAVIS AND SUTCLIFFE (1985)
NORMAL	E	1140.6 ± 2 KROGH ET AL. (1987)

A Intrusive into Mamainse Point Formation

B Rhyolite from Osler Group

C Porphyry from base of Osler Group

D Logan sill

E Great Abitibi dyke

Fig. 12.2: In-situ mechanism for generating highly differentiated zones (i.e. unit 2) within wide dykes. Settling of mineral grains in dyke interior (fine stippled pattern) leaves evolved residue (coarse stippled pattern). Diagram from Fahrig (1985); see also Kretz et al. (1985).

Fig. 12.3: Models for the origin of unit 2. Unit 2 could have evolved by in-situ differentiation (1), or by differentiation in an external magma chamber and subsequent emplacement into the dyke. This external chamber could be located at depth (2), along strike (3) or above (4).

Fig. 12.4: Emplacement of unit 2 downwards from an overlying funnel intrusion. Several mechanisms are proposed: (1) a drop in the level of unit 1 magma in the feeder dyke would allow overlying unit 1 magma to descend to fill its place. A drop in the unit 1 magma could also be caused by continued opening or lengthening of the dyke conduit while the magma volume within the dyke remained constant. (2) alternatively crystal charged plumes of unit 2 could 'rain' down (Shirley, 1987) from the overlying intrusion into the dyke-conduit, accumulate in a synformal pattern and displace unit 1 material.

It is important to evaluate whether sufficient room existed above the emplacement level of the GAD for an overlying trough-shaped intrusion. While the depth of exposure of the GAD is unknown, estimates of about 7 km depth were obtained for both a 2150 Ma and a 1250 Ma dyke in the Superior Province using a paleomagnetic technique (Buchan and Schwarz, 1981; Schwarz, 1977). Many trough-shaped intrusion such as the Skaergaard and Muskox Intrusion were emplaced at shallower levels such that their bases were at depths no greater than about 5 km (e.g. Hall, 1987, p. 106; Smith et al., 1967 assuming a 50° angle of exposure; Irvine, 1980).

Fig. 12.5: Histogram of dyke-dip data from the Hearst-Matachewan swarm in the vicinity of the GAD at traverse 7. Data was collected from dykes located along a north-south highway (HWY 144) and are grouped in terms of their location north or south of the GAD.

CHAPTER 13

CONCLUSIONS

13.1 OVERVIEW OF PETROLOGIC AND MAGNETIC DATA

The Great Abitibi Dyke (GAD) extends across the Abitibi belt from the Kapuskasing Structural Zone to the Grenville Front and has a total length of more than 700 km (Fig. 1.1). Throughout most of its length, it has a trend of approximately 70° . Near its northeast end (at long. $75^{\circ}45'$) the GAD appears to split into two branches; the northern and southern 'branches' have trends of approximately 55° and 65° , respectively (map in back pocket; Section 11.2). Chemical and petrographic data confirm that the northern branch is a continuation of the GAD, but also suggest that the southern 'branch' may not be part of the GAD. The width of the GAD varies from 100 to 250 m. It is widest at its mid-length portion and thins towards both the northeast and southwest (Fig. 11.5 and Table 11.4).

The dip of the GAD varies between 70° S and 70° N but on average is nearly vertical (Fig. 11.5; Table 11.4). Adjacent en-echelon segments commonly have quite different dips. The non-vertical dip at traverse 7 was shown to be primary, while at other traverses, non-vertical dips are shown to be the consequence of subsequent block tilting. Paleomagnetic data (Chapter 9) indicate that block-tilting was mainly restricted to the ends of the GAD, i.e. adjacent to the Grenville Front and the KSZ.

The GAD is composed of rock types ranging from olivine gabbro to

monzodiorite and has not been affected by in-situ host rock contamination (Section 3.2). On the basis of whole rock and mineral chemistry the dyke can be divided into two natural compositional groups, units 1 and 2 (Figs. 2.6, 2.7 and 3.1). Rocks of unit 1 occur along the entire length of the dyke, while unit 2 rocks form the interior region over about half of the length of the dyke (Fig. 3.2 and 3.3).

Unit 1 consists entirely of olivine gabbro and can be further sub-divided at traverse 7 on the basis of field relationships and minor differences in chemical composition into at least two sub-units, 1a and 1b (Fig. 2.1). At traverse 4, rocks of unit 1 are cut by aphanitic dykelets that also belong to unit 1. The composition of unit 2 ranges between olivine gabbro and monzodiorite. Paleomagnetic data and the lack of chilled internal contacts between units 1 and 2 indicate that there was a maximum time gap of approximately a hundred years between the emplacement of the two units.

The variation in whole-rock and mineral chemistry throughout units 1 and 2 can be attributed to crystal fractionation of chiefly olivine and plagioclase from a parental magma corresponding to the composition of chilled margin samples. Linear relationships between the molar $100 \cdot \text{Mg}/(\text{Mg} + \text{Fe})$ ratio of olivine and augite, the molar $100 \cdot \text{Ca}/(\text{Ca} + \text{Na} + \text{K})$ ratio of feldspar, and the whole-rock incompatible element content, allow calibration of the mineral chemistry in terms of the degree of evolution of the parental magma. Unit 1 rocks were formed by 0% to 50% fractionation of the parental magma while unit 2

rocks were produced by an additional 20% fractionation. Compositional asymmetry across the dyke at traverse 7 indicates that the dyke conduit (at this traverse) was non-vertical during crystallization.

Unit 1 rocks could have crystallized from the parental magma as a closed system (because the areal-abundance of fractionated and cumulate rocks approximately balance). However, derivation of unit 2 magma from the parental magma requires extensive loss of plagioclase and olivine, but this fractionate is not exposed at the surface. It may have been carried to greater depth in the dyke or may have been left behind during derivation of unit 2 in an external chamber.

Unit 2 also shows a systematic variation in composition along strike, attributed to variation in the relative abundances of plagioclase and mafic minerals. With respect to the parent magma, samples from the northeast end of unit 2 appear to have been formed by fractionation of a greater proportion of mafic minerals and smaller proportion of plagioclase than samples from the southwest end of unit 2. The present exposure level of the GAD is thought to vary slightly along the dyke as a consequence of regional block tilting of a few degrees such that shallowest exposure levels are along the mid-length of the dyke. Thus the along-dyke variation in unit 2 chemistry may represent an oblique slice through a vertically-differentiated body.

The compositions of coexisting olivine and augite suggest temperatures of equilibration ranging between 1200° and less than 800°. Unit 2 rocks have the lower temperatures. The compositions of coexisting Fe-Ti oxides follow the FMQ buffer and have equilibrium

temperatures between 650° and 750°.

Field mapping and anisotropy of magnetic susceptibility (AMS) data suggest that throughout unit 2, tabular feldspar defines a synformal foliation pattern with axial plane aligned approximately parallel to the plane of the dyke (Figs. 2.3, 2.4 and 8.7). At traverse 7, discontinuous mafic-rich zones within unit 2 are generally parallel to the feldspar foliation. They may represent disrupted modal layering (Plate 2.2).

Unit 1 rocks become more evolved both towards the interior and along the strike to the northeast. The AMS data also suggest that unit 1 was emplaced along a horizontal trajectory. These data are consistent with derivation of the parental magma in the mantle beneath the Keweenawan rift to the southwest and emplacement into the dyke along a sub-horizontal trajectory.

The parental magma was not a primary mantle magma but underwent significant differentiation prior to emplacement. Trace element discriminant diagrams and spidergrams show that the GAD is similar to a within-plate-basalt (WPB) and probably was derived from an OIB-type mantle reservoir. With respect to an idealized OIB pattern the GAD exhibits a positive anomaly in Ba, Eu, K, P and Ti and a negative anomaly in Hf and Zr. These anomalies probably derive from the mantle source area but could also be due to magma differentiation en-route through the crust.

13.2 EMPLACEMENT HISTORY

The Great Abitibi dyke was emplaced at 1140 Ma (Krogh et al.,

1987) which is similar in age to all the following: Keweenawan igneous rocks, the compressive phase of the Grenville Orogeny and the intrusive age of carbonatites in the vicinity of the KSZ.

Details on emplacement models of the KSZ are not well-constrained. The model most consistent with these data involves a magma source underlying the Keweenawan rift and emplacement of the parental magma along a sub-horizontal trajectory towards the northeast. Unit 1 differentiated from the parental magma in situ over a range of 50% crystallization. Unit 2 magma was derived from the parental magma either in-situ through settling of crystals to deeper parts of the dyke or by differentiation in an external chamber and subsequent emplacement into the dyke.

It is proposed that the GAD was emplaced as a consequence of asthenospheric upwelling associated with the Keweenawan rift and a favourable orientation of fractures caused both by Grenville compression and a zone of pre-existing weakness along the extension of the southern boundary fault of the KSZ.

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APPENDICES

APPENDIX 1: PETROLOGIC DATA: ANALYTICAL PROCEDURE, ACCURACY AND PRECISION

A1.1 MODAL MINERAL ANALYSIS

The mineral modes of 44 samples were determined by point-counting one thin section from each sample. Generally, 1000 points were counted in a grid-pattern over an area of approximately 8 cm². The precision of the measurements was evaluated by duplicate counts on 4 thin sections (Table A1.1). The large uncertainties, up to about 10% (of the amount present), probably result from the coarse grain size relative to the area analyzed on the thin section.

A1.2 MINERAL CHEMISTRY

Mineral chemistry was determined using quantitative wavelength dispersive analysis on a Cambridge Microscan 5 electron microprobe. Operating conditions include a specimen current of 50 nA as measured on pure Fe, a beam diameter of 2 to 3 μ m, an accelerating potential of 15 kV and 20 second counting times. Exceptions are as follows: an accelerating potential of 20-25 kV was used for all determinations of Ni, some measurements of Ca in olivine and some measurements of Fe, Mn, Ti, Mg and Al in Fe-Ti oxides; counting times of 30 seconds were used for measurements of Ni and Ca in olivine and sometimes Ti, Na and Cr in augite. The data was reduced to oxide weight percentages using the program EMPADR-7 (Rucklidge, 1967; Rucklidge and Gasparrini, 1969). Estimated 2s errors relative to amount present are: $\pm 1\%$ for abundances greater than 30%, $\pm 2\%$ to 3% for abundances between 30% and 10%, $\pm 3\%$ to 7% for abundances between 10% and 1%, $\pm 7\%$ to 10% for abundances between 1% and 0.5% and greater than $\pm 10\%$ for abundances less than 0.5% (P. Jones, pers. comm. 1989).

In order to identify mineral zonation, individual minerals were analyzed both in their core and rim regions and at intermediate distances between core and rim. Rim analyses were measured no closer to the grain margin than about 15-30 μ m. This distance was chosen to reduce the likelihood of having the analyzed volume overlap into the adjacent mineral phases. Core and intermediate regions are defined as the grain centre and about two-thirds of the distance towards the margin, respectively. Only grains larger than about 0.2 mm were tested for mineral zonation.

There are 249 analyses of olivine from 34 samples, 162 feldspar analyses from 16 samples, 129 augite analyses from 18 samples, 41 titanomagnetite analyses from 10 samples, 35 ilmenite analyses from 10 samples, 13 orthopyroxene analyses from 3 samples and 11 analyses of biotite, prehnite, chamosite and pectolite.

A1.3 WHOLE-ROCK CHEMISTRY

A1.3.1 Introduction

The major elements and selected trace elements, Ba, Cr, Zr, Sr, Rb, Y, Nb, Zn, Ni, and V for all samples were analyzed by X-Ray

fluorescence at the University of Ottawa Geochemistry Laboratory. Forty seven samples were also analyzed at the University of Toronto for LOI (loss-on-ignition), using a muffle furnace, and for the rare earth elements (REE), Co, Ta, Sc, Hf and Th, using instrumental neutron activation analysis (INAA).

A1.3.2 Sample Preparation

All samples except those analyzed using INAA, were crushed to powder in a tungsten ring mill (shatterbox). Owing to the increased INAA background interference caused by tungsten contamination (Barnes and Gorton, 1984; Hickson and Juras, 1986) those samples analyzed by INAA were crushed in either a Cr-steel mill or in an agate mill. Cr values for samples crushed in the Cr-steel mill were discarded.

A1.3.3 XRF Analysis

The XRF analyses were made using a Phillips PW1410/20 AHP instrument fitted with a rhodium excitation tube. Data were reduced using correction coefficients modified after those used at the Geological Survey of Canada (R. Rousseau, pers. comm., 1987). Samples were prepared as fused glass discs composed of 1.300 g of sample, 0.433 g of Li_2CO_3 and 3.900 g of $\text{Li}_2\text{B}_4\text{O}_7$. A single disc was analyzed for each sample except as a check on precision.

Analytical precision was evaluated by analyzing two discs each from 7 samples (Table A1.2). Analytical accuracy and precision was tested by analyses of international standards (Table A1.3). These include multiple analyses of DR-N as well as single analyses of other standards (Abbey, 1973).

A1.3.4 Instrumental Neutron Activation Analysis (INAA)

Samples were analysed by INAA at the University of Toronto following the procedure of Barnes and Gorton (1984). Samples were weighed out into sealed plastic sachets, irradiated in a SLOWPOKE II reactor under a neutron flux of $2.5 \times 10^{11} \text{ n cm}^{-2} \text{ s}^{-1}$ and counted at both 7 and 40 days after irradiation using a 20% effective coaxial intrinsic Ge detector. Two, in-house standards, UTB1 and G80-55 from the University of Toronto (Barnes and Gorton, 1984) were included in each run. UTB1 was used as a standard and the data was processed so as to yield the accepted value for UTB1. G80-55 was employed as monitor, i.e. as an independent check of analytical accuracy. Repeat measurements of this monitor have high precision (low 2s errors) and generally agree with accepted values to within one standard deviation (Table A1.4). The exceptions are Co, Hf, Ta and Th.

A1.3.5 Loss-On-Ignition

Loss-on-ignition (LOI) data were collected at the University of Toronto. Samples were weighed out into a platinum crucible, heated in a muffle furnace under a through-flowing nitrogen atmosphere and re-weighed after heating. The samples were heated for 0.5 hours at temperatures of $1000 \pm 100 \text{ }^\circ\text{C}$ (2s uncertainty). The difference in weight before and after heating equals the LOI. Table A1.5 shows

repeat analyses on the University of Toronto in-house standard, UTB1, on sample duplicates and on TH35, an internal standard used by T. Hart formerly of the University of Toronto (Hart, 1984)

A1.3.6 Summary of Uncertainties in XRF and INAA Analyses

Analytical uncertainties from the XRF and INAA are summarized in Table A1.6.

Table A1.1: Precision of modal mineral analyses.

SAMPLE #	8428.07	8428.07	8401.60	8401.60
OLIVINE	4.4	6.8	7.0	7.0
PLAGIOCLASE	70.0	65.1	51.1	54.3
ALKALI FELDSPAR	2.8	1.1	1.5	3.0
TOTAL FELDSPAR	72.8	66.2	52.6	57.3
AUGITE	12.8	18.2	19.8	20.8
FE-TI OXIDES	5.4	5.2	16.9	10.3
APATITE	1.2	1.6	2.4	3.8
QUARTZ	-	-	-	-
ORTHOPYROXENE	-	-	-	-
BIOTITE	2.1	1.4	0.8	0.4
OTHER	1.3	0.6	0.5	0.4
TOTAL	100	100	100	100
FELDSPAR RATIO (ALKALI/TOTAL %)	3.9	1.7	2.9	5.2

SAMPLE #	8201.03	8201.03	8201.01	8201.01
OLIVINE	4.7	6.7	10.5	17.2
PLAGIOCLASE	43.0	-	71.6	60.0
ALKALI FELDSPAR	18.6	-	0.6	0.3
TOTAL FELDSPAR	61.6	54.9	72.2	60.3
AUGITE	15.4	16.1	8.5	10.6
FE-TI OXIDES	5.1	7.0	5.2	6.0
APATITE	2.9	4.1	0.7	2.9
QUARTZ	1.3	0.7	-	-
ORTHOPYROXENE	2.7	3.1	-	-
BIOTITE	2.0	1.0	2.0	2.5
OTHER	4.3	6.5	0.9	0.5
TOTAL	100	100	100	100
FELDSPAR RATIO (ALKALI/TOTAL %)	30.2	-	0.8	0.5

	Standard Deviation
OLIVINE	2.6 vol %
PLAGIOCLASE	5.3 vol %
ALKALI FELDSPAR	0.9 vol %
TOTAL FELDSPAR	5.6 vol %
AUGITE	2.1 vol %
FE-TI OXIDES	2.4 vol %
APATITE	1 vol %
BIOTITE	0.5 vol %

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Table A1.2: Estimate of Analytical Precision of the XRF Using Duplicate Analyses of Samples From the GAD. Each analysis is from a separately weighed, prepared and fused disc.

	RE84-18-04		RE84-18-11		RE84-01-19	
SiO ₂	46.22	46.20	55.97	56.19	44.58	44.23
Al ₂ O ₃	18.45	18.47	20.86	20.92	10.87	10.85
Fe ₂ O ₃ T	13.27	13.26	4.32	4.36	21.66	21.31
MgO	4.01	3.97	0.40	0.38	4.03	3.99
CaO	9.15	9.16	5.80	5.88	8.28	8.18
Na ₂ O	3.58	3.65	5.94	5.93	3.45	3.29
K ₂ O	1.23	1.23	2.47	2.49	1.75	1.74
TiO ₂	3.93	3.95	0.86	0.83	4.04	3.94
P ₂ O ₅	0.67	0.73	0.55	0.53	1.84	1.80
MnO	0.16	0.16	0.07	0.07	0.30	0.30
Ba	858.	842.	1388.	1408.	1442.	1415.
Cr	-	-	-	-	-	-
Zr	110.	109.	283.	257.	199.	198.
Sr	940.	947.	875.	893.	532.	535.
Rb	16.	15.	25.	43.	24.	28.
Y	23.	23.	26.	40.	45.	43.
Nb	18.	18.	26.	23.	32.	34.
Zn	143.	293.	116.	136.	174.	258.
Ni	21.	12.	0.	0.	0.	0.
V	-	-	-	-	-	-

	RE84-01-46		RE82-06-03		RE84-07-02	
SiO ₂	44.74	44.73	44.94	45.16	45.54	45.36
Al ₂ O ₃	16.90	17.07	16.55	16.62	16.15	16.13
Fe ₂ O ₃ T	15.10	15.10	14.17	13.97	15.20	14.91
MgO	6.70	6.69	3.93	3.95	6.54	6.43
CaO	9.14	9.02	10.70	10.64	8.75	8.68
Na ₂ O	2.92	2.86	3.38	3.58	3.22	3.41
K ₂ O	0.64	0.64	1.10	1.10	0.97	0.96
TiO ₂	3.48	3.44	3.87	3.87	3.57	3.56
P ₂ O ₅	0.63	0.57	1.94	1.95	0.85	0.73
MnO	0.18	0.18	0.18	0.18	0.19	0.19
Ba	624.	612.	946.	948.	845.	845.
Cr	-	-	-	-	-	-
Zr	81.	78.	115.	113.	109.	112.
Sr	878.	871.	920.	923.	834.	832.
Rb	7.	16.	11.	8.	11.	11.
Y	23.	18.	32.	33.	24.	21.
Nb	13.	13.	20.	20.	15.	16.
Zn	108.	110.	102.	119.	87.	112.
Ni	72.	72.	10.	0.	53.	53.
V	-	-	342.	347.	272.	256.

(Continued on next page)

RE82-07-08

SiO ₂	45.84	46.16
Al ₂ O ₃	17.41	17.50
Fe ₂ O ₃ T	14.16	14.04
MgO	4.80	4.81
CaO	9.20	9.25
Na ₂ O	3.46	3.56
K ₂ O	1.11	1.11
TiO ₂	3.75	3.78
P ₂ O ₅	0.74	0.77
MnO	0.18	0.18
Ba	895.	861.
Cr	-	-
Zr	109.	113.
Sr	921.	922.
Rb	11.	12.
Y	23.	22.
Nb	18.	18.
Zn	91.	92.
Ni	27.	22.
V	294.	293.

	Standard	Deviation
SiO ₂	0.16	%
Al ₂ O ₃	0.06	%
Fe ₂ O ₃ T	0.14	%
MgO	0.03	%
CaO	0.05	%
Na ₂ O	0.09	%
K ₂ O	0.01	%
TiO ₂	0.03	%
P ₂ O ₅	0.05	%
MnO	0	%
Ba	14	ppm
Zr	7	ppm
Sr	6	ppm
Rb	6	ppm
Y	4	ppm
Nb	1	ppm
Zn	47	ppm
Ni	4	ppm
V	7	ppm

Calculated from pairs of analyses using the equation
(Kretz, 1985)

$S = \text{SQRT}[\text{sum}((x1-x2)(x1-x2)/2N)]$
where for all elements $N = 7$ except for V and Ni where $N = 3$

Table A1.3: Estimate of Accuracy and Precision of XRF Analyses

Repeat Measurements on the International Standard, DR-N

Element	N	Mean (2*SD)	Accepted Value
SiO ₂	23	52.81 (0.31)	52.98
Al ₂ O ₃	23	17.60 (0.17)	17.56
Fe ₂ O ₃ T	23	9.68 (0.06)	9.72
MgO	23	4.25 (0.20)	4.41
CaO	23	6.97 (0.06)	7.07
Na ₂ O	23	2.97 (0.19)	3.00
K ₂ O	23	1.71 (0.03)	1.70
TiO ₂	23	1.06 (0.05)	1.09
P ₂ O ₅	23	0.15 (0.04)	0.25
MnO	23	0.22 (0.01)	0.22
Ba	23	393. (51.)	390.
Cr	18	45. (8.)	42.
Zr	23	130. (4.)	125.
Sr	23	391. (12.)	400.
Rb	23	69. (5.)	70.
Y	23	29. (4.)	30.
Nb	23	4. (3.)	6.
Zn	23	151. (20.)	145.
Ni	23	18. (20.)	22.
V	18	230. (40.)	230.

Accepted values from Abbey (1983).

(Continued on next page)

Analysis of Other International Standards

	MRG		SY		BR	
	MEASURED	ACCEPTED	MEASURED	ACCEPTED	MEASURED	ACCEPTED
SiO ₂	38.91	(39.32)	59.92	(60.10)	38.74	(38.39)
Al ₂ O ₃	8.57	(8.50)	12.04	(12.12)	10.15	(10.25)
Fe ₂ O ₃ T	17.81	(17.82)	6.24	(6.28)	13.01	(12.90)
MgO	13.77	(13.49)	2.72	(2.70)	13.22	(13.35)
CaO	14.85	(14.77)	7.87	(7.98)	13.80	(13.87)
Na ₂ O	0.68	(0.71)	4.18	(4.34)	3.08	(3.07)
K ₂ O	0.18	(0.18)	4.44	(4.48)	1.39	(1.41)
TiO ₂	3.83	(3.69)	0.13	(0.14)	2.69	(2.61)
P ₂ O ₅	0.00	(0.06)	0.38	(0.43)	1.09	(1.05)
MnO	0.17	(0.17)	0.33	(0.32)	0.21	(0.20)
Ba	49.	(50.)	447.	(460.)	1084.	(1050.)
Cr	465.	(450.)	2.	(12.)	338.	(380.)
Zr	97.	(100.)	276.	(280.)	282.	(250.)
Sr	258.	(260.)	265.	(273.)	1342.	(1320.)
Rb	5.	(8.)	219.	(220.)	43.	(47.)
Y	18.	(16.)	137.	(130.)	38.	(30.)
Nb	18.	(20.)	19.	(23.)	104.	(100.)
Zn	196.	(190.)	254.	(250.)	170.	(150.)
Ni	177.	(195.)	18.	(10.)	258.	(260.)
V	513.	(520.)	58.	(52.)	281.	(240.)

	BCR-1		SDC-1		BHVO-1	
	MEASURED	ACCEPTED	MEASURED	ACCEPTED	MEASURED	ACCEPTED
SiO ₂	53.97	(54.53)	65.87	(66.15)	49.89	(49.90)
Al ₂ O ₃	13.41	(13.72)	15.79	(15.75)	13.78	(13.85)
Fe ₂ O ₃ T	13.59	(13.41)	7.00	(6.85)	12.33	(12.23)
MgO	3.50	(3.48)	1.75	(1.70)	7.25	(7.31)
CaO	6.94	(6.97)	1.42	(1.39)	11.44	(11.33)
Na ₂ O	3.34	(3.30)	2.13	(2.10)	2.43	(2.29)
K ₂ O	1.70	(1.70)	3.27	(3.24)	0.52	(0.54)
TiO ₂	2.25	(2.26)	0.99	(1.00)	2.78	(2.69)
P ₂ O ₅	0.29	(0.36)	0.11	(0.18)	0.15	(0.28)
MnO	0.19	(0.18)	0.12	(0.12)	0.17	
Ba	646.	(680.)	588.	(650.)	146.	(135.)
Cr	20.	(15.)	67.	(66.)	286.	(300.)
Zr	179.	(185.)	310.	(300.)	163.	(180.)
Sr	402.	(330.)	186.	(180.)	399.	(420.)
Rb	44.	(47.)	129.	(120.)	7.	(10.)
Y	39.	(40.)	41.	(42.)	27.	(27.)
Nb	6.	(19.)	14.	(18.5)	17.	(19.)
Zn	122.	(125.)	121.	(105.)	90.	(105.)
Ni	0.	(10.)	27.	(36.)	98.	(120.)
V	437.	(420.)	99.	(105.)	351.	(320.)

Accepted values from Abbey (1983).

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Table A1.4: Estimate of Accuracy and Precision of INAA data

	Standard		Monitor		Coefficient of Variation = SD/Mean (see Kretz, 1985)	
	UTBI (Accepted Value) [†]	G80-55 (Accepted Value) [†]	G80-55 (Measured Value) Mean (2*SD)	N	determined on G80-55 ²	determined on UTBI ²
Ce	60.5	229.	222. (12.)	5	2.7%	3.9%
Co	48.	1.4	0.6 (0.2)	5	16.7%	2.5%
Eu	2.4	3.1	3.2 (0.4)	5	6.3%	2.1%
Hf	4.6	19.	16.4 (1.4)	5	4.3%	6.0%
La	26.7	92.	94. (4.)	4	2.1%	2.5%
Lu	0.62	3.9	4.1 (0.4)	4	4.9%	9.8%
Nd	32.	122.	126. (8.)	4	3.2%	6.5%
Sc	38.	2.1	2.0 (0.2)	5	5.0%	2.0%
Sm	8.	32.5	32.1 (2.2)	4	3.4%	3.1%
Ta	1.02	4.1	3.3 (0.4)	5	6.1%	8.0%
Tb	1.2	6.3	5.7 (1.4)	5	12.3%	7.2%
Th	4.3	11.6	11.3 (0.4)	5	1.8%	5.5%
Yb	4.	25.7	26.2 (2.0)	4	3.8%	4.3%

[†] Accepted values from Barnes and Gorton (1984).

¹ From repeat measurements on G80-55 (used as a monitor for analyses of this thesis).

² From Table 1 in Barnes and Gorton (1984).

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APPENDIX 2: MODAL MINERAL ANALYSES FROM THIN SECTION

A2.1 EXPLANATION OF TABLE A2.1

Along Position is the along-dyke position measured in kilometres. The origin is that used in Fig. 1.2 and has been arbitrarily chosen. **Across Position** is the across-dyke position measured in metres from the centre line of the dyke. Positive/negative values are towards the north/south contact. **Thickness** is dyke thickness measured in metres. **Total Feldspar** is total feldspar (alkali feldspar plus plagioclase). **Fe-Ti Oxides** include titanomagnetite plus ilmenite. **Other** includes minor primary minerals such as baddeleyite and zircon, as well as deuteric or secondary minerals such as amphibole, chlorite (including chamosite), prehnite and pectolite. The dyke tends to be only weakly altered and alteration minerals were distinguished in the mode (under **Other**) only where the primary mineral could not be reliably identified. **Feldspar Ratio** is the percentage ratio of alkali feldspar to total feldspar.

Table A2.1: Modal mineral analyses from thin sections.

SAMPLE #	8428.01	8428.03	¹ 8428.07	8204.14	8203.14	8203.15
TRAVERSE #	2	2	2	4	5	5
ALONG POS.	173	173	173	206	216	216
ACROSS POS.	-14.10	-25.30	17.15	-54.70	-46.75	-43.50
THICKNESS	88.5	88.5	88.5	137.5	109.0	109.0
UNIT	1	1	1	1	1	1
OLIVINE	11.7	5.2	5.6	14.1	17.0	15.5
PLAGIOCLASE	58.0	65.3	67.7	70.5	59.9	69.7
ALKALI FELDSPAR	1.9	2.3	2.0	0.4	0.2	0.9
TOTAL FELDSPAR	59.9	67.6	69.5	70.9	60.1	70.6
AUGITE	16.0	19.0	15.5	9.7	12.2	5.4
FE-TI OXIDES	6.5	2.8	5.3	3.9	8.0	5.8
APATITE	1.7	2.1	1.4	0.8	1.4	0.2
QUARTZ	-	-	-	-	-	-
ORTHOPYROXENE	-	-	-	-	-	-
BIOTITE	2.1	1.6	1.8	0.6	0.8	1.7
OTHER	2.0	1.7	1.0	-	0.4	0.8
TOTAL	99.9	100.0	100.1	100.0	99.9	100.0
FELDSPAR RATIO (ALKALI/TOTAL %)	3.2	3.4	2.9	0.6	0.3	1.3

SAMPLE #	8203.12	8401.02	8401.06	8401.07	8401.08	8401.11
TRAVERSE #	5	7	7	7	7	7
ALONG POS.	216	243	243	243	243	243
ACROSS POS.	-9.35	-101.00	-88.75	-77.10	-71.00	-46.15
THICKNESS	109.0	209.5	209.5	209.5	209.5	209.5
UNIT	2	1	1	1	2	2
OLIVINE	3.9	31.0	11.6	9.2	13.7	6.5
PLAGIOCLASE	29.5	56.5	61.7	47.8	28.9	49.6
ALKALI FELDSPAR	24.6	0.4	0.6	2.8	12.0	6.6
TOTAL FELDSPAR	54.1	56.9	62.3	50.6	40.9	56.2
AUGITE	22.7	7.0	15.2	20.9	24.1	21.9
FE-TI OXIDES	10.0	3.7	8.5	11.7	9.1	5.0
APATITE	4.6	0.2	1.5	7.0	5.5	3.7
QUARTZ	-	-	-	-	-	-
ORTHOPYROXENE	-	-	-	-	-	-
BIOTITE	3.3	1.1	0.7	0.6	5.0	5.4
OTHER	1.5	0.1	0.2	-	1.7	1.3
TOTAL	100.1	100.0	100.0	100.0	100.0	100.0
FELDSPAR RATIO (ALKALI/TOTAL %)	45.5	1.8	1.0	5.5	29.3	11.7

¹ Average of Two Analyses

(Continued on next page)

Table A2.1

SAMPLE #	8401.13	8401.15	8401.18	8401.20	8401.57	8401.22
TRAVERSE #	7	7	7	7	7	7
ALONG POS.	243	243	243	243	243	243
ACROSS POS.	-28.60	-6.80	25.65	36.75	61.64	63.50
THICKNESS	209.5	209.5	209.5	209.5	209.5	209.5
UNIT	2	2	2	2	2	2
OLIVINE	7.8	8.6	11.5	7.6	13.3	7.9
PLAGIOCLASE	49.7	43.9	32.5	32.2	39.7	46.6
ALKALI FELDSPAR	11.5	18.4	12.1	13.4	5.3	8.8
TOTAL FELDSPAR	61.2	62.3	44.6	45.6	45.0	55.4
AUGITE	13.1	16.4	21.7	28.1	27.4	22.1
FE-TI OXIDES	5.6	4.9	10.1	7.6	9.3	8.4
APATITE	2.8	2.9	5.0	3.9	3.1	3.4
QUARTZ	-	-	-	-	-	-
ORTHOPYROXENE	-	-	-	-	-	-
BIOTITE	6.9	3.9	6.3	6.9	1.7	1.7
OTHER	2.6	1.0	0.8	0.3	0.2	1.1
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0
FELDSPAR RATIO (ALKALI/TOTAL %)	18.8	29.5	27.1	29.4	11.8	15.9

SAMPLE #	8401.58	8401.59	8401.23	¹ 8401.60	8401.61	8401.62
TRAVERSE #	7	7	7	7	7	7
ALONG POS.	243	243	243	243	243	243
ACROSS POS.	66.05	67.65	69.85	67.93	73.29	74.51
THICKNESS	209.5	209.5	209.5	209.5	209.5	209.5
UNIT	1	1	1	1	1	1
OLIVINE	3.4	6.3	6.9	7.0	11.5	6.9
PLAGIOCLASE	49.7	47.8	45.5	52.7	57.6	60.4
ALKALI FELDSPAR	5.7	6.1	8.6	2.3	1.4	4.5
TOTAL FELDSPAR	55.4	53.9	54.1	55.0	59.0	64.9
AUGITE	24.2	24.1	22.5	20.3	13.3	16.7
FE-TI OXIDES	10.2	11.4	10.9	13.6	12.2	8.6
APATITE	5.5	2.0	2.8	3.1	1.5	1.8
QUARTZ	-	-	-	-	-	-
ORTHOPYROXENE	-	-	-	-	-	-
BIOTITE	1.0	1.9	2.6	0.6	2.3	1.1
OTHER	0.3	0.4	0.3	0.5	0.2	-
TOTAL	100.0	100.0	100.1	100.1	100.0	100.0
FELDSPAR RATIO (ALKALI/TOTAL %)	10.3	11.3	15.9	4.2	2.4	6.9

¹ Average of Two Analyses

(Continued on next page)

Table A2.1

SAMPLE #	8401.24	8401.54	8401.55	8205.04	8201.03	8201.02
TRAVERSE #	7	7	7	8	11	11
ALONG POS.	243	243	243	290	337	337
ACROSS POS.	79.50	88.25	89.75	42.75	32.75	53.35
THICKNESS	209.5	209.5	209.5	220.0	160.5	160.5
UNIT	1	1	1	1	2	1
OLIVINE	3.6	21.0	14.9	4.6	5.7	14.4
PLAGIOCLASE	48.5	61.9	70.6	-	40.7	65.9
ALKALI FELDSPAR	8.1	0.4	0.3	-	17.6	1.5
TOTAL FELDSPAR	56.6	62.3	70.9	62.4	58.3	67.4
AUGITE	31.9	7.3	4.8	10.2	15.8	3.9
FE-TI OXIDES	4.1	4.7	8.3	8.3	6.1	6.8
APATITE	2.7	0.7	0.6	2.9	3.5	3.2
QUARTZ	-	-	-	4.4	1.0	-
ORTHOPYROXENE	-	-	-	0.6	2.0	-
BIOTITE	0.9	3.6	0.5	0.5	1.5	4.3
OTHER	0.2	0.4	-	6.0	5.3	-
TOTAL	100.0	100.0	100.0	99.9	100.1	100.0
FELDSPAR RATIO (ALKALI/TOTAL %)	14.3	0.6	14.3	0.6	14.3	0.6

SAMPLE #	8201.01	8206.03	8418.03	8418.15	8207.15	8418.17
TRAVERSE #	11	12	14	14	14	14
ALONG POS.	337	416	427	427	427	427
ACROSS POS.	75.15	-60.50	-78.65	-52.50	-35.50	6.00
THICKNESS	160.5	185.0	220.0	220.0	220.0	220.0
UNIT	1	1	1	2	2	2
OLIVINE	13.9	7.6	2.8	6.7	0.0	4.4
PLAGIOCLASE	65.7	53.3	63.4	46.1	56.3	66.0
ALKALI FELDSPAR	0.6	0.5	0.5	17.7	3.6	4.4
TOTAL FELDSPAR	66.3	53.8	63.9	63.8	59.9	70.4
AUGITE	9.6	21.3	18.4	11.3	32.1	11.1
FE-TI OXIDES	5.6	9.3	8.2	9.5	5.6	4.8
APATITE	1.8	5.0	3.9	4.6	2.4	1.7
QUARTZ	-	-	-	-	-	0.2
ORTHOPYROXENE	-	-	-	-	-	-
BIOTITE	2.3	2.9	2.4	2.9	-	0.8
OTHER	0.6	-	0.4	1.2	-	6.6
TOTAL	100.1	99.9	100.0	100.0	100.0	100.0
FELDSPAR RATIO (ALKALI/TOTAL %)	0.9	0.9	0.8	27.7	6.0	6.3

¹ Average of Two Analyses

(Continued on next page)

Table A2.1

SAMPLE #	8418.13	8418.11	8207.06	8207.04	8208.08	8208.06
TRAVERSE #	14	14	14	14	15	15
ALONG POS.	427	427	427	427	614	614
ACROSS POS.	15.50	25.00	83.00	108.85	-60.00	-30.65
THICKNESS	220.0	220.0	220.0	220.0	148.0	148.0
UNIT	1	2	1	1	1	1
OLIVINE	8.0	0.2	8.8	13.3	13.4	1.6
PLAGIOCLASE	69.8	-	63.9	64.7	61.0	68.4
ALKALI FELDSPAR	5.9	-	0.5	1.7	1.0	1.1
TOTAL FELDSPAR	75.7	82.6	64.4	66.0	62.0	69.5
AUGITE	6.9	10.0	14.2	8.5	14.9	10.9
FE-TI OXIDES	3.7	2.6	9.5	5.9	6.4	9.7
APATITE	4.5	1.5	1.8	1.0	0.8	3.0
QUARTZ	-	-	-	-	-	-
ORTHOPYROXENE	-	-	-	-	-	-
BIOTITE	0.9	1.1	1.6	4.2	1.8	1.8
OTHER	0.3	2.0	-	1.1	0.7	1.5
TOTAL	100.0	100.0	100.1	100.0	100.0	100.0
FELDSPAR RATIO (ALKALI/TOTAL %)	7.8	-	0.8	2.0	1.6	1.6

SAMPLE #	8208.02	8209.06
TRAVERSE #	15	16
ALONG POS.	614	702
ACROSS POS.	1.00	32.10
THICKNESS	148.0	85.0
UNIT	1	1
OLIVINE	7.5	8.5
PLAGIOCLASE	63.8	71.1
ALKALI FELDSPAR	0.6	0.4
TOTAL FELDSPAR	64.4	71.5
AUGITE	14.3	10.2
FE-TI OXIDES	7.1	8.3
APATITE	4.8	1.2
QUARTZ	-	-
ORTHOPYROXENE	-	-
BIOTITE	1.4	0.3
OTHER	0.5	-
TOTAL	100.0	100.0
FELDSPAR RATIO (ALKALI/TOTAL %)	0.9	0.6

APPENDIX 3: MINERAL ANALYSES

A3.1 EXPLANATION OF TABLE A3.1

Along Position, Across Position, Thickness are defined as in Appendix 2. Circle# denotes circled areas on the thin section and Grain# identifies different grains within the circle. Rim-Core locates the analyzed spot with respect to the Core, Intermediate and Rim of grains. Rim analyses were done between 15 and 50 microns of the grain margin. Intermediate was located about two-thirds of the way towards the Rim from the Core. Adjacent is the mineral type which is nearest (adjacent) to the location of the Rim or Intermediate analysis. In Table A3.1 groups of analyses from the same thin section are delimited by the vertical lines.

Mineral stoichiometry was calculated using oxide wt% divided by molecular weight. Fo# for olivine, and En# for clinopyroxene and orthopyroxene are calculated as: $100 \cdot \text{MgO} / (\text{MgO} + \text{FeO})$. An# for feldspar is calculated as: $100 \cdot \text{CaO} / (\text{CaO} + 2 \cdot \text{Na}_2\text{O} + 2 \cdot \text{K}_2\text{O})$. Usp# for titanomagnetite is calculated from:

$$100 \cdot 3 \cdot (\text{SiO}_2 + \text{TiO}_2) / (\text{SiO}_2 + \text{TiO}_2 + 2 \cdot \text{Al}_2\text{O}_3 + 2 \cdot \text{V}_2\text{O}_3 + 2 \cdot \text{Cr}_2\text{O}_3 + \text{FeO} + \text{MnO} + \text{MgO} + \text{CaO} + \text{ZnO}).$$

Ilm# for ilmenite is calculated from:

$$\text{ILM\#} = 100 \cdot 2 \cdot (\text{SiO}_2 + \text{TiO}_2) / (\text{SiO}_2 + \text{TiO}_2 + \text{Al}_2\text{O}_3 + \text{V}_2\text{O}_3 + \text{Cr}_2\text{O}_3 + \text{FeO} + \text{MnO} + \text{MgO} + \text{CaO} + \text{ZnO})$$

The formulas for Usp# and Ilm# are from the computer program ILMAG (Rucklidge and Gasparrini, 1969). For some samples Usp# and Ilm# calculated as above were compared with Usp# and Ilm# calculated using the procedure of Bohlen and Essene (1977); the results agree favourably.

While all the chemical data is quoted to two decimal places, the analytical uncertainties are such that the data should not necessarily be considered accurate to two decimal places particularly for minor elements (See Appendix 1).

Table A3.1

OLIVINE ANALYSES																	OLIVINE ANALYSES																	OLIVINE ANALYSES																
Sample#	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07																				
Traverse#	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2																				
Along Pos.	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173																				
Across Pos.	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15																				
Thickness	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5																				
Circles	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00																				
Grains	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00																				
Rim-Core	CORE	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM																				
Adjacent	FE-TI	OX.	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR																				
SiO ₂	33.35	32.44	33.60	33.60	33.04	32.52	34.90	34.67	35.33	34.49	32.62	34.81	34.23	35.68	35.79	35.68	35.79	35.68	35.79	35.68	35.79	35.68	35.79	35.68	35.79	35.68	35.79	35.68	35.79	35.68																				
TiO ₂	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--																				
Al ₂ O ₃	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--																				
Cr ₂ O ₃	47.56	52.41	46.13	50.15	52.42	39.70	40.21	39.31	40.72	51.17	40.35	42.13	36.50	36.57	36.57	36.50	36.57	36.50	36.57	36.50	36.57	36.50	36.57	36.50	36.57	36.50	36.57	36.50	36.57	36.50																				
FeO _T	0.88	0.96	0.83	0.91	0.92	0.62	0.65	0.60	0.60	0.95	0.63	0.66	0.52	0.53	0.53	0.52	0.53	0.52	0.53	0.52	0.53	0.52	0.53	0.52	0.53	0.52	0.53	0.52	0.53	0.52																				
NaO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--																				
NIU	17.34	13.92	18.78	15.79	13.62	24.13	23.67	24.38	23.09	14.92	23.41	22.37	26.86	26.50	26.50	26.86	26.50	26.86	26.50	26.86	26.50	26.86	26.50	26.86	26.50	26.86	26.50	26.86	26.50	26.86																				
NaO	0.42	0.33	0.21	0.26	0.25	0.32	0.30	0.31	0.24	0.22	0.29	0.33	0.31	0.29	0.29	0.31	0.29	0.31	0.29	0.31	0.29	0.31	0.29	0.31	0.29	0.31	0.29	0.31	0.29	0.31																				
CaO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--																				
Na ₂ O	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--																				
K ₂ O	99.55	100.10	99.54	100.10	99.73	99.67	99.50	99.93	99.13	99.88	99.49	99.72	99.87	99.69	99.69	99.87	99.69	99.87	99.69	99.87	99.69	99.87	99.69	99.87	99.69	99.87	99.69	99.87	99.69	99.87																				
Total	39.38	32.12	42.04	35.94	31.65	51.99	51.20	52.50	50.26	34.19	50.83	48.62	56.74	56.36	56.36	56.74	56.36	56.74	56.36	56.74	56.36	56.74	56.36	56.74	56.36	56.74	56.36	56.74	56.36	56.74																				
FeO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--																				

OLIVINE ANALYSES																	OLIVINE ANALYSES																	OLIVINE ANALYSES																
Sample#	8428.03	8428.03	8428.03	8428.03	8428.03	8428.03	8428.03	8428.03	8428.03	8428.03	8428.03	8428.03	8428.03	8428.03	8428.03	8428.03	8428.03	8428.03	8428.03	8428.03	8428.03	8428.03	8428.03	8428.03	8428.03	8428.03	8428.03	8428.03	8428.03	8428.03																				
Traverse#	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2																				
Along Pos.	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173																				
Across Pos.	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3																				
Thickness	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5																				
Circles	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00																				
Grains	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00																				
Rim-Core	CORE	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM																				
Adjacent	FE-TI	OX.	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR																				
SiO ₂	35.50	34.71	33.71	33.83	34.22	34.18	33.69	33.78	31.66	31.58	32.06	35.67	35.54	35.25	35.54	35.25	35.54	35.25	35.54	35.25	35.54	35.25	35.54	35.25	35.54	35.25	35.54	35.25	35.54	35.25																				
TiO ₂	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--																				
Al ₂ O ₃	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--																				
Cr ₂ O ₃	36.09	39.72	42.62	41.98	43.25	43.05	46.45	45.54	53.43	53.20	53.82	36.08	34.83	35.98	35.98	35.98	35.98	35.98	35.98	35.98	35.98	35.98	35.98	35.98	35.98	35.98	35.98	35.98	35.98	35.98																				
FeO _T	0.49	0.62	0.67	0.68	0.72	0.72	0.64	0.82	1.03	0.99	1.04	0.51	0.48	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55																				
NaO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--																				
NIU	26.88	24.83	22.58	23.28	20.51	21.26	17.66	19.11	12.80	12.60	11.77	27.26	28.51	27.52	27.52	27.52	27.52	27.52	27.52	27.52	27.52	27.52	27.52	27.52	27.52	27.52	27.52	27.52	27.52	27.52																				
NaO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--																				
CaO	0.29	0.30	0.23	0.30	0.31	0.36	0.35	0.38	0.80	0.97	0.94	0.22	0.33	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21																					
Na ₂ O	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--																				
K ₂ O	99.25	100.20	99.82	100.10	99.02	99.56	98.98	99.62	99.71	99.31	99.71	99.75	99.75	99.53	99.53	99.53	99.53	99.53	99.53	99.53	99.53	99.53	99.53	99.53	99.53	99.53	99.53	99.53	99.53	99.53																				
Total	57.03	52.70	48.56	49.70	45.80	46.81	40.39	42.78	29.92	29.68	28.04	57.18	59.29	57.68	57.68	57.68	57.68	57.68	57.68	57.68	57.68	57.68	57.68	57.68	57.68	57.68	57.68	57.68	57.68	57.68																				
FeO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--																				

Table A3.1

Sampled	OLIVINE ANALYSES									
	8203.13	8401.46	8401.46	8401.46	8401.55	8401.55	8401.55	8401.55	8401.55	8401.06
Traverse	5	7	7	7	7	7	7	7	7	7
Along.Fos.	216	243	243	243	243	243	243	243	243	243
Across.Fos.	-34.35	104.7	104.7	104.7	89.75	89.75	89.75	89.75	89.75	-88.75
Thickness	109	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5
Circle	2.00	1.00	1.00	1.00	1.00	2.00	2.00	4.00	1.00	3.00
Grain	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Rim-Core	CORE	--	--	RIN	CORE	CORE	RIN	CORE	CORE	RIN
Adjacent	--	--	--	--	--	--	--	--	--	--
SiO ₂	35.46	36.95	36.91	36.78	36.18	35.66	35.61	36.11	34.13	35.46
TiO ₂	--	--	--	--	--	--	--	--	--	--
Al ₂ O ₃	--	--	--	--	--	--	--	--	--	--
Cr ₂ O ₃	--	--	--	--	--	--	--	--	--	--
FeO [†]	35.97	29.13	29.27	29.24	31.60	36.72	36.18	32.98	44.88	37.41
MnO	0.55	0.54	0.55	0.54	0.45	0.46	0.60	0.49	0.77	0.53
NiO	0.01	--	--	--	0.00	0.00	0.02	0.00	0.04	0.00
MgO	27.00	31.94	32.26	32.24	30.25	26.52	27.00	29.34	20.20	26.49
BaO	--	--	--	--	--	--	--	--	--	--
CaO	0.37	0.09	0.10	0.09	0.31	0.20	0.20	0.27	0.19	0.24
Na ₂ O	--	--	--	--	--	--	--	--	--	--
K ₂ O	--	--	--	--	--	--	--	--	--	--
Total	99.35	98.66	99.09	98.90	99.79	99.69	99.60	99.19	100.20	100.10
Fee	57.22	66.15	66.26	66.27	63.04	56.2	57.08	61.32	44.51	55.79

Sampled	OLIVINE ANALYSES									
	8401.06	8401.06	8401.06	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13
Traverse	7	7	7	7	7	7	7	7	7	7
Along.Fos.	243	243	243	243	243	243	243	243	243	243
Across.Fos.	-88.75	-88.75	-88.75	-88.75	-88.75	-88.75	-88.75	-88.75	-88.75	-88.75
Thickness	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5
Circle	3.00	4.00	4.00	1.00	3.00	4.00	4.00	4.00	5.00	3.00
Grain	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Rim-Core	CORE	CORE	RIN	CORE	CORE	RIN	RIN	CORE	CORE	RIN
Adjacent	--	--	--	--	--	--	--	--	--	--
SiO ₂	35.37	35.41	33.70	33.85	30.54	31.02	30.48	31.11	31.23	31.27
TiO ₂	--	--	--	--	--	--	--	--	--	--
Al ₂ O ₃	--	--	--	--	--	--	--	--	--	--
Cr ₂ O ₃	--	--	--	--	--	--	--	--	--	--
FeO [†]	37.05	37.19	45.74	44.27	61.50	59.01	62.65	57.62	59.93	56.99
MnO	0.48	0.51	0.83	0.77	1.39	1.36	1.47	1.24	1.27	1.23
NiO	0.00	0.00	0.00	0.00	0.03	0.04	0.03	0.04	0.03	0.01
MgO	26.34	26.73	19.71	20.45	6.36	8.00	5.28	9.19	7.66	9.60
BaO	--	--	--	--	--	--	--	--	--	--
CaO	0.30	0.32	0.33	0.36	0.45	0.46	0.34	0.46	0.33	0.34
Na ₂ O	--	--	--	--	--	--	--	--	--	--
K ₂ O	--	--	--	--	--	--	--	--	--	--
Total	99.53	100.20	100.30	99.70	100.30	99.90	100.30	99.67	100.50	99.62
Fee	55.89	56.16	43.44	45.15	15.56	19.46	13.06	22.13	18.55	23.09

(Continued on next page)

Table A3.1

Sample	OLIVINE ANALYSES									
	8401.54	8401.54	8401.54	8401.54	8401.54	8401.54	8401.54	8401.54	8401.54	8401.54
Traverse	7	7	7	7	7	7	7	7	7	7
Along Pot.	243	243	243	243	243	243	243	243	243	243
Across Pot.	88.25	88.25	88.25	88.25	88.25	88.25	88.25	88.25	88.25	88.25
Thickness	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5
Circle	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Grain	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Rim-Core	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM
Adjacent	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR
SiO ₂	35.87	35.83	36.08	36.70	35.14	35.01	35.14	34.97	32.64	32.24
TiO ₂	--	--	--	--	--	--	--	--	--	--
Al ₂ O ₃	--	--	--	--	--	--	--	--	--	--
Cr ₂ O ₃	--	--	--	--	--	--	--	--	--	--
FeO	35.15	34.62	35.11	35.47	38.11	37.90	38.31	38.34	52.60	52.48
MnO	0.51	0.47	0.50	0.46	0.58	0.58	0.62	0.60	1.07	1.07
NiO	0.03	0.02	0.04	0.01	0.05	0.03	0.03	0.03	0.00	0.01
MgO	28.03	27.66	27.79	27.68	25.42	25.54	25.26	25.11	14.13	13.89
BaO	--	--	--	--	--	--	--	--	--	--
CaO	0.17	0.29	0.21	0.26	0.19	0.18	0.24	0.26	0.43	0.39
Na ₂ O	--	--	--	--	--	--	--	--	--	--
K ₂ O	--	--	--	--	--	--	--	--	--	--
Total	99.76	98.90	99.73	100.60	99.49	99.24	99.61	99.31	100.90	100.10
Fe	58.70	58.74	58.51	58.17	54.31	54.57	54.02	53.95	32.37	35.65

Sample	OLIVINE ANALYSES									
	8401.22	8401.22	8401.22	8401.22	8401.23	8401.23	8401.23	8401.23	8401.23	8401.23
Traverse	7	7	7	7	7	7	7	7	7	7
Along Pot.	243	243	243	243	243	243	243	243	243	243
Across Pot.	63.5	63.5	63.5	69.85	69.85	69.85	69.85	69.85	61.64	61.64
Thickness	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5
Circle	3.00	4.00	4.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Grain	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Rim-Core	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM
Adjacent	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR
SiO ₂	32.91	31.83	32.10	32.77	33.13	33.43	33.45	33.11	32.70	32.90
TiO ₂	--	--	--	--	--	--	--	--	--	--
Al ₂ O ₃	--	--	--	--	--	--	--	--	--	--
Cr ₂ O ₃	--	--	--	--	--	--	--	--	--	--
FeO	51.04	52.97	53.52	48.05	49.46	46.40	47.61	49.02	49.38	50.28
MnO	1.03	1.13	1.18	0.89	0.93	0.87	0.89	0.90	0.89	0.95
NiO	0.00	0.00	0.03	0.00	0.01	0.00	0.01	0.00	0.00	0.00
MgO	15.32	14.20	13.04	17.27	16.37	18.41	17.95	16.97	16.20	15.75
BaO	--	--	--	--	--	--	--	--	--	--
CaO	0.34	0.40	0.36	0.39	0.31	0.37	0.33	0.35	0.34	0.33
Na ₂ O	--	--	--	--	--	--	--	--	--	--
K ₂ O	--	--	--	--	--	--	--	--	--	--
Total	100.60	100.50	100.20	99.37	100.20	99.49	100.20	100.40	99.52	100.20
Fe	34.85	32.33	30.27	39.04	37.10	41.42	40.19	38.15	36.89	35.82

Sample	OLIVINE ANALYSES									
	8401.57	8401.57	8401.57	8401.57	8401.57	8401.57	8401.57	8401.57	8401.57	8401.57
Traverse	7	7	7	7	7	7	7	7	7	7
Along Pot.	243	243	243	243	243	243	243	243	243	243
Across Pot.	61.64	61.64	61.64	61.64	61.64	61.64	61.64	61.64	61.64	61.64
Thickness	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5
Circle	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Grain	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Rim-Core	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM
Adjacent	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR
SiO ₂	32.91	32.90	32.57	32.57	32.57	32.57	32.57	32.57	32.57	32.57
TiO ₂	--	--	--	--	--	--	--	--	--	--
Al ₂ O ₃	--	--	--	--	--	--	--	--	--	--
Cr ₂ O ₃	--	--	--	--	--	--	--	--	--	--
FeO	51.04	50.28	50.56	50.56	50.56	50.56	50.56	50.56	50.56	50.56
MnO	1.03	0.95	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91
NiO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MgO	15.32	15.75	15.23	15.23	15.23	15.23	15.23	15.23	15.23	15.23
BaO	--	--	--	--	--	--	--	--	--	--
CaO	0.34	0.33	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Na ₂ O	--	--	--	--	--	--	--	--	--	--
K ₂ O	--	--	--	--	--	--	--	--	--	--
Total	100.60	100.20	99.66	99.66	99.66	99.66	99.66	99.66	99.66	99.66
Fe	34.85	35.82	34.93	34.93	34.93	34.93	34.93	34.93	34.93	34.93

(Continued on next page)

Table A3.1

Sample	OLIVINE ANALYSES					OLIVINE ANALYSES					OLIVINE ANALYSES					OLIVINE ANALYSES				
	8401.57	8401.20	8401.20	8401.20	8401.20	8401.20	8401.20	8401.20	8401.20	8401.20	8401.24	8401.24	8401.24	8401.24	8401.24	8401.24	8401.24	8401.24	8401.24	8401.58
Traverse	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Along Pos.	243	243	243	243	243	243	243	243	243	243	243	243	243	243	243	243	243	243	243	243
Across Pos.	61.64	36.75	36.75	36.75	36.75	36.75	36.75	36.75	36.75	36.75	78.5	78.5	78.5	78.5	78.5	78.5	78.5	78.5	78.5	66.05
Thickness	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5
Circle	4.00	1.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Grain	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Rim-Core	RIM	CORE	CORE	CORE	CORE	CORE	CORE	CORE	CORE	CORE	CORE	CORE	CORE	CORE	CORE	CORE	CORE	CORE	CORE	CORE
Adjacent	FELDSPAR	---	---	---	---	---	---	---	---	---	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR
SiO ₂	32.23	31.63	31.85	31.63	31.36	31.63	31.63	31.28	31.28	31.28	34.00	33.70	34.37	34.08	34.32	34.15	34.15	34.15	34.15	33.53
TiO ₂	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Al ₂ O ₃	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Cr ₂ O ₃	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
FeO	52.88	56.37	56.28	56.07	58.39	55.97	58.45	58.45	58.45	58.45	41.38	42.24	40.94	43.07	41.41	41.27	41.27	41.27	41.27	45.74
NaO	1.04	1.20	1.17	1.15	1.33	1	1.29	1.29	1.29	1.29	0.61	0.68	0.69	0.70	0.64	0.65	0.65	0.65	0.65	0.77
NiO	0.00	0.02	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.01	---	---	---	---	---	---	---	---	---	---
MgO	13.26	10.38	10.65	10.69	8.46	10.63	8.21	8.21	8.21	8.21	22.45	22.30	23.27	21.36	23.14	23.02	23.02	23.02	23.02	19.33
BaO	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
CaO	0.33	0.53	0.44	0.51	0.44	0.48	0.36	0.36	0.36	0.36	0.36	0.22	0.34	0.32	0.33	0.25	0.25	0.25	0.25	0.40
Na ₂ O	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
K ₂ O	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Total	99.74	100.10	100.40	100.10	99.99	99.90	99.59	99.59	99.59	99.59	98.81	99.14	99.61	99.53	99.84	99.33	99.33	99.33	99.33	99.78
For	30.88	24.71	25.22	25.36	20.52	25.29	20.02	20.02	20.02	20.02	49.16	48.47	50.32	46.91	49.89	49.85	49.85	49.85	49.85	42.96

Sample	OLIVINE ANALYSES					OLIVINE ANALYSES					OLIVINE ANALYSES					OLIVINE ANALYSES				
	8401.58	8401.58	8401.58	8401.58	8401.58	8401.58	8401.58	8401.58	8401.58	8401.58	8401.08	8401.08	8401.08	8401.08	8401.08	8401.08	8401.08	8401.08	8401.08	8401.08
Traverse	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Along Pos.	243	243	243	243	243	243	243	243	243	243	243	243	243	243	243	243	243	243	243	243
Across Pos.	66.05	66.05	66.05	66.05	66.05	66.05	66.05	66.05	66.05	66.05	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5
Thickness	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5
Circle	1.00	1.00	3.00	3.00	4.00	4.00	4.00	4.00	4.00	4.00	2.00	3.00	3.00	4.00	4.00	6.00	6.00	6.00	6.00	6.00
Grain	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Rim-Core	RIM	RIM	CORE	CORE	CORE	CORE	CORE	CORE	CORE	CORE	RIM	CORE	CORE	CORE	CORE	CORE	CORE	CORE	CORE	CORE
Adjacent	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR	FELDSPAR
SiO ₂	32.89	33.72	34.16	34.11	34.25	34.01	31.18	31.18	31.18	31.18	31.14	31.58	30.94	31.16	31.17	30.57	30.57	30.57	30.57	30.57
TiO ₂	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Al ₂ O ₃	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Cr ₂ O ₃	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
FeO	50.68	47.56	44.63	45.05	44.37	45.11	58.78	58.78	58.78	58.78	58.49	56.29	58.72	58.82	58.41	61.54	61.54	61.54	61.54	60.59
NaO	0.93	0.87	0.78	0.75	0.77	0.77	1.43	1.43	1.43	1.43	1.41	1.25	1.39	1.38	1.31	1.37	1.37	1.37	1.37	1.40
NiO	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
MgO	15.34	18.03	20.18	20.31	20.32	19.88	8.43	8.43	8.43	8.43	8.74	10.65	8.48	8.46	8.34	5.82	5.82	5.82	5.82	6.59
BaO	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
CaO	0.31	0.30	0.39	0.29	0.39	0.34	0.58	0.58	0.58	0.58	0.53	0.57	0.46	0.51	0.59	0.49	0.49	0.49	0.49	0.53
Na ₂ O	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
K ₂ O	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Total	100.10	100.50	100.10	100.50	100.10	100.10	100.40	100.40	100.40	100.40	100.30	100.30	99.99	100.30	99.82	99.78	99.78	99.78	99.78	100.10
For	35.04	40.32	44.62	44.56	44.94	43.99	20.35	20.35	20.35	20.35	21.03	25.21	20.47	20.40	20.28	14.42	14.42	14.42	14.42	16.15

(Continued on next page)

Table A3.1

Sample	OLIVINE ANALYSES					OLIVINE ANALYSES					OLIVINE ANALYSES					OLIVINE ANALYSES				
	8401.08	8401.07	8401.07	8401.07	8401.07	8401.07	8401.07	8401.07	8401.07	8401.07	8401.07	8401.07	8401.07	8401.07	8401.07	8401.07	8401.07	8401.07	8401.07	8401.07
Traverse	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Along Pen.	243	243	243	243	243	243	243	243	243	243	243	243	243	243	243	243	243	243	243	243
Across Pen.	-71	-77.1	-77.1	-77.1	-77.1	-77.1	-77.1	-77.1	-77.1	-77.1	-77.1	-77.1	-77.1	-77.1	-77.1	-77.1	-77.1	-77.1	-77.1	-77.1
Thickness	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5
Circle	6.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Grain	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Rim-Core	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM
Adjacent	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.
SiO ₂	29.89	34.25	34.37	33.35	34.04	33.77	33.68	33.50	33.81	33.78	33.30	33.70	35.46	35.65	35.70	35.46	35.65	35.70	35.46	35.65
TiO ₂	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Al ₂ O ₃	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cr ₂ O ₃	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
FeO	64.15	41.02	40.90	45.67	42.09	42.26	40.88	41.69	44.99	45.25	45.52	36.53	36.73	36.16	36.53	36.73	36.16	36.53	36.73	36.16
MnO	1.58	0.61	0.59	0.72	0.64	0.67	0.55	0.60	0.71	0.71	0.73	0.63	0.64	0.69	0.63	0.64	0.69	0.63	0.64	0.69
NiO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
MgO	3.87	22.80	22.62	18.90	21.95	21.73	22.50	22.28	19.17	19.76	19.09	27.06	26.91	27.09	27.06	26.91	27.09	27.06	26.91	27.09
BeO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CaO	0.34	0.39	0.39	0.30	0.21	0.41	0.35	0.40	0.32	0.30	0.44	0.07	0.09	0.09	0.07	0.09	0.09	0.07	0.09	0.09
Na ₂ O	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
K ₂ O	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Total	99.83	99.07	98.85	98.94	98.94	98.84	97.94	98.46	99.00	99.80	99.07	99.99	99.84	99.67	99.99	99.84	99.67	99.99	99.84	99.67
Fee	9.71	49.76	49.64	42.44	48.17	47.82	49.52	48.78	43.16	43.76	42.77	56.90	56.63	57.17	56.90	56.63	57.17	56.90	56.63	57.17

Sample	OLIVINE ANALYSES					OLIVINE ANALYSES					OLIVINE ANALYSES					OLIVINE ANALYSES				
	8404.14	8404.14	8404.14	8404.14	8404.14	8404.14	8404.14	8404.14	8404.14	8404.14	8404.14	8404.14	8404.14	8404.14	8404.14	8404.14	8404.14	8404.14	8404.14	8404.14
Traverse	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
Along Pen.	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330
Across Pen.	-93.075	-93.075	-93.075	-93.075	-93.075	-93.075	-93.075	-93.075	-93.075	-93.075	-93.075	-93.075	-93.075	-93.075	-93.075	-93.075	-93.075	-93.075	-93.075	-93.075
Thickness	186.55	186.55	186.55	186.55	186.55	186.55	186.55	186.55	186.55	186.55	186.55	186.55	186.55	186.55	186.55	186.55	186.55	186.55	186.55	186.55
Circle	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Grain	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Rim-Core	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM
Adjacent	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.
SiO ₂	35.33	35.42	35.75	36.28	35.78	31.67	31.31	31.61	31.31	31.24	31.48	31.28	31.83	31.39	31.28	31.83	31.39	31.28	31.83	31.39
TiO ₂	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Al ₂ O ₃	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cr ₂ O ₃	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
FeO	37.52	37.77	35.43	34.69	34.99	58.77	58.02	58.50	58.78	59.27	58.18	59.04	55.78	57.43	59.04	55.78	57.43	59.04	55.78	57.43
MnO	0.69	0.70	0.64	0.62	0.60	1.09	1.06	1.09	1.06	1.10	1.06	1.17	1.07	1.09	1.17	1.07	1.09	1.17	1.07	1.09
NiO	--	--	--	--	--	0.01	0.01	0.03	0.03	0.02	0.02	0.02	0.00	0.02	0.02	0.00	0.02	0.02	0.00	0.02
MgO	26.05	25.99	27.66	28.18	27.62	9.17	9.41	9.07	8.94	8.75	9.68	8.17	11.03	9.60	8.17	11.03	9.60	8.17	11.03	9.60
BeO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CaO	0.09	0.09	0.10	0.07	0.09	0.16	0.17	0.19	0.17	0.16	0.12	0.23	0.28	0.24	0.23	0.28	0.24	0.23	0.28	0.24
Na ₂ O	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
K ₂ O	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Total	94.67	94.98	99.59	99.84	99.08	100.90	99.98	100.50	100.30	100.60	100.70	99.89	99.99	99.70	99.89	99.99	99.70	99.89	99.99	99.70
Fee	55.40	55.09	58.15	59.14	58.45	21.76	22.40	21.60	21.4	20.93	22.75	19.79	26.06	22.95	19.79	26.06	22.95	19.79	26.06	22.95

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Table A3.1

Sample	OLIVINE ANALYSES									
	8201.04	8207.04	8207.04	8207.04	8207.04	8207.04	8207.04	8207.04	8207.04	8207.15
Traverse	11	14	14	14	14	14	14	14	14	14
Along For.	337	427	427	427	427	427	427	427	427	427
Across For.	-15.65	108.85	108.85	108.85	108.85	108.85	108.85	108.85	108.85	-35.5
Thickness	160.5	220	220	220	220	220	220	220	220	220
Circle	3.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	1.00
Grades	2.00	1.00	2.00	4.00	5.00	1.00	1.00	3.00	1.00	1.00
Rim-Core	CORE	RIM	---	---	---	CORE	---	---	CORE	RIM
Adjacent	---	OLIVINE	---	---	---	---	---	---	---	---
SiO ₂	31.43	35.12	34.86	34.95	35.15	34.81	34.93	34.87	34.75	34.81
TiO ₂	---	---	---	---	---	---	---	---	---	---
Al ₂ O ₃	---	---	---	---	---	---	---	---	---	---
Cr ₂ O ₃	---	---	---	---	---	---	---	---	---	---
FeO ¹	57.48	39.11	40.74	39.99	39.27	40.20	39.58	40.36	41.34	38.07
MnO	1.13	0.69	0.76	0.74	0.70	0.76	0.71	0.75	0.75	0.68
NiO	0.01	---	---	---	---	---	---	---	---	---
MgO	9.31	25.19	23.32	24.46	25.07	23.85	24.18	23.90	22.94	24.96
CaO	---	---	---	---	---	---	---	---	---	---
Na ₂ O	0.27	0.14	0.21	0.12	0.11	0.22	0.21	0.15	0.16	0.38
K ₂ O	---	---	---	---	---	---	---	---	---	---
Total	99.63	100.30	99.89	100.30	100.30	99.84	99.60	100.00	100.40	98.90
Fe	22.40	53.14	50.50	52.15	53.22	51.39	52.12	51.34	51.80	53.88

Sample	OLIVINE ANALYSES									
	8207.15	8207.15	8207.15	8207.15	8207.15	8207.15	8418.16	8418.16	8418.16	8418.15
Traverse	14	14	14	14	14	14	14	14	14	14
Along For.	427	427	427	427	427	427	427	427	427	427
Across For.	-35.5	-35.5	-35.5	-35.5	-35.5	-35.5	-21.5	-21.5	-21.5	-52.5
Thickness	220	220	220	220	220	220	220	220	220	220
Circle	1.00	2.00	4.00	4.00	5.00	5.00	1.00	1.00	3.00	4.00
Grades	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Rim-Core	CORE	RIM	CORE	CORE	RIM	CORE	CORE	CORE	CORE	RIM
Adjacent	---	---	---	---	---	---	FELDSPAR	---	---	FELDSPAR
SiO ₂	34.88	34.54	34.62	35.11	34.99	35.49	32.79	32.86	32.55	30.44
TiO ₂	---	---	---	---	---	---	---	---	---	---
Al ₂ O ₃	---	---	---	---	---	---	---	---	---	---
Cr ₂ O ₃	---	---	---	---	---	---	---	---	---	---
FeO ¹	37.72	40.95	40.01	36.53	38.76	37.72	50.57	50.07	53.52	53.57
MnO	0.67	0.88	0.84	0.63	0.73	0.71	0.95	0.96	1.07	1.22
NiO	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.02
MgO	25.12	22.48	23.40	26.43	24.40	25.26	14.91	15.83	12.00	12.69
CaO	---	---	---	---	---	---	---	---	---	---
Na ₂ O	0.39	0.40	0.41	0.32	0.39	0.33	0.31	0.30	0.29	0.37
K ₂ O	---	---	---	---	---	---	---	---	---	---
Total	98.78	99.25	99.29	99.02	99.47	99.51	99.53	100.00	99.44	98.32
Fe	54.27	49.45	51.03	56.32	57.97	54.41	34.44	36.04	28.55	29.64

(Continued on next page)

Table A3.1

OLIVINE ANALYSES																	OLIVINE ANALYSES																	OLIVINE ANALYSES																
Sample	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15																				
Traverse	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14																			
Along Pot.	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427																			
Across Pot.	-52.5	-52.5	-52.5	-52.5	-52.5	-52.5	-52.5	-52.5	-52.5	-52.5	-52.5	-52.5	-52.5	-52.5	-52.5	-52.5	-52.5	-52.5	-52.5	-52.5	-52.5	-52.5	-52.5	-52.5	-52.5	-52.5	-52.5	-52.5	-52.5	-52.5	-52.5																			
Thickness	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220																			
Circle	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00																			
Grates	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00																			
Rim-Core	CORE	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM																			
Adjacent	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--																			
SiO ₂	30.91	31.20	32.67	32.99	32.94	33.32	33.32	33.32	33.32	33.32	33.32	33.32	33.32	33.32	33.32	33.32	33.32	33.32	33.32	33.32	33.32	33.32	33.32	33.32	33.32	33.32	33.32	33.32	33.32	33.32	33.32																			
Al ₂ O ₃	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--																			
Cr ₂ O ₃	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--																			
FeO	50.26	54.15	51.56	52.01	50.75	52.11	52.11	52.11	52.11	52.11	52.11	52.11	52.11	52.11	52.11	52.11	52.11	52.11	52.11	52.11	52.11	52.11	52.11	52.11	52.11	52.11	52.11	52.11	52.11	52.11	52.11																			
MnO	1.03	1.24	1.08	1.12	1.07	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16																			
NiO	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00																			
MgO	15.87	12.58	14.53	14.34	15.33	13.99	13.99	13.99	13.99	13.99	13.99	13.99	13.99	13.99	13.99	13.99	13.99	13.99	13.99	13.99	13.99	13.99	13.99	13.99	13.99	13.99	13.99	13.99	13.99	13.99	13.99																			
NaO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--																		
CaO	0.37	0.52	0.35	0.38	0.44	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47																			
Na ₂ O	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--																		
K ₂ O	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--																		
Total	98.44	99.71	100.20	100.90	100.50	101.10	101.10	101.10	101.10	101.10	101.10	101.10	101.10	101.10	101.10	101.10	101.10	101.10	101.10	101.10	101.10	101.10	101.10	101.10	101.10	101.10	101.10	101.10	101.10	101.10	101.10																			
Fee	36.01	29.28	33.43	32.95	34.99	32.36	32.36	32.36	32.36	32.36	32.36	32.36	32.36	32.36	32.36	32.36	32.36	32.36	32.36	32.36	32.36	32.36	32.36	32.36	32.36	32.36	32.36	32.36	32.36	32.36	32.36																			

Sample	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	
Traverse	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	
Along Pot.	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	
Across Pot.	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	
Thickness	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	
Circle	4.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	
Grates	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
Rim-Core	CORE	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM
Adjacent	31.81	32.18	32.09	33.03	32.39	35.52	34.36	34.36	34.36	34.36	34.36	34.36	34.36	34.36	34.36	34.36	34.36	34.36	34.36	34.36	34.36	34.36	34.36	34.36	34.36	34.36	34.36	34.36	34.36	34.36	34.36	
SiO ₂	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Al ₂ O ₃	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cr ₂ O ₃	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
FeO	55.67	50.61	51.95	50.37	51.27	38.04	39.51	39.51	39.51	39.51	39.51	39.51	39.51	39.51	39.51	39.51	39.51	39.51	39.51	39.51	39.51	39.51	39.51	39.5								

(Continued on next page)

Table A1.5: Precision of Loss-on-Ignition Data

Repeat Measurements on UTB1

LOI (wt%) 1.10 1.10 1.10 1.05 0.80
SD = 0.13

Duplicate Measurements on:

LOI (wt%) RE8401.02 RE8405.06 RE8406.03
 0.43 0.37 0.59
SD = 0.07 0.31 0.29 0.49

Duplicate Measurements on TH35

LOI (wt%) 4.65 4.65 4.65 4.65 4.60
SD = 0.02

UTB1 described in Barnes and Gorton (1984)
TH35 described in Hart (1984)

Calculated from pairs of analyses using the equation (Kretz, 1985)
 $SD = \sqrt{\frac{\sum (x_1 - x_2)^2}{2N}}$
where $N = 3$.

Table A1.6: Summary of analytical uncertainties in whole-rock chemistry. Each value obtained from either Table A1.2, A1.3 or A1.4. For some elements more than one estimate of uncertainty was available and, in these cases, the larger value was used. The only exceptions were Ba, Zn and Ni for which outlier values excessively increased the uncertainty. The uncertainties in Ba and Ni are taken from Table A1.2 and that of Zn is from Table A1.3.

	2S	$\bar{X}$	Coefficient of Variation ($100 \cdot S/\bar{X}$)
SiO ₂	0.32	47	0.34
Al ₂ O ₃	0.17	15	0.57
Fe ₂ O ₃ T	0.28	14	1.00
Fe ₂ O ₃	0.06	3	1.00
FeO	0.20	10	1.00
MgO	0.20	4	2.50
CaO	0.10	9	0.56
Na ₂ O	0.19	3.5	2.71
K ₂ O	0.03	1.5	1.00
TiO ₂	0.06	3.2	0.94
P ₂ O ₅	0.10	1.2	4.17
MnO	0.01	0.2	2.50
Ba	28	1200	1.17
Cr	8	40	10.00
Zr	14	130	5.38
Sr	12	800	0.75
Rb	12	20	30.00
Y	8	30	13.33
Nb	3	20	7.50
Zn	20	150	6.70
Ni	8	20	20.00
V	40	200	10.00
Ce	4.7	60	3.90
Co	2	37	2.70
Eu	0.13	3	2.10
Hf	0.36	3	6.00
La	1.5	30	2.50
Lu	0.08	0.4	9.75
Nd	5	40	6.50
Sc	1	25	2.00
Sm	0.62	10	3.10
Ta	0.32	1.8	8.89
Tb	0.14	1	7.20
Th	0.22	2	5.50
Yb	0.17	2	4.30

Table A3.1

Sample	OLIVINE ANALYSES										OLIVINE ANALYSES									
	8209.02	8209.02	8209.02	8209.02	8209.02	8209.02	8209.02	8209.02	8209.02	8209.02	8209.04	8209.04	8209.04	8209.04	8209.04	8209.04	8209.04	8209.04	8209.04	8209.04
Transverse	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16
Along Pos.	702	702	702	702	702	702	702	702	702	702	702	702	702	702	702	702	702	702	702	702
Across Pos.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Thickness	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85
Circle	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Grain	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Rim-Core	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM
Adjacent	FELDSPAR	FE-TI OX.	OLIVINE	OLIVINE	OLIVINE	OLIVINE	OLIVINE	OLIVINE	OLIVINE	OLIVINE	OLIVINE	OLIVINE	OLIVINE	OLIVINE	OLIVINE	OLIVINE	OLIVINE	OLIVINE	OLIVINE	OLIVINE
SiO ₂	35.02	34.32	35.40	35.61	35.25	34.44	34.59	34.59	34.59	34.59	33.41	33.97	34.05	35.60	35.79	35.19	34.53	34.53	34.53	34.53
TiO ₂	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Al ₂ O ₃	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cr ₂ O ₃	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
FeO	40.56	43.72	39.06	39.49	41.13	44.31	43.13	43.13	43.13	43.13	45.21	43.92	45.72	36.81	35.18	38.44	40.88	40.88	40.88	40.88
MnO	0.68	0.83	0.68	0.64	0.72	0.87	0.81	0.81	0.81	0.81	0.90	0.83	0.93	0.62	0.54	0.62	0.72	0.72	0.72	0.72
NiO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
MgO	23.66	21.09	24.73	24.65	23.06	20.38	21.37	21.37	21.37	21.37	19.68	20.60	19.21	26.55	27.77	24.98	23.04	23.04	23.04	23.04
BaO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CaO	0.33	0.33	0.32	0.32	0.35	0.31	0.37	0.37	0.37	0.37	0.33	0.36	0.33	0.31	0.34	0.32	0.30	0.30	0.30	0.30
Na ₂ O	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
K ₂ O	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Total	100.30	100.30	100.20	100.70	100.50	100.30	100.30	100.30	100.30	100.30	99.53	99.69	100.20	99.88	99.63	99.55	99.46	99.46	99.46	99.46
Fee	50.97	46.23	54.01	52.66	49.98	45.04	46.89	46.89	46.89	46.89	43.68	45.53	42.82	56.24	58.45	53.66	50.11	50.11	50.11	50.11

Sample	OLIVINE ANALYSES										OLIVINE ANALYSES									
	8209.04	8209.04	8209.04	8209.04	8209.04	8209.04	8209.04	8209.04	8209.04	8209.04	8209.06	8209.06	8209.06	8209.06	8209.06	8209.06	8209.06	8209.06	8209.06	8209.06
Transverse	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16
Along Pos.	702	702	702	702	702	702	702	702	702	702	702	702	702	702	702	702	702	702	702	702
Across Pos.	17.35	17.35	17.35	17.35	17.35	17.35	17.35	17.35	17.35	17.35	32.1	32.1	32.1	32.1	32.1	32.1	32.1	32.1	32.1	32.1
Thickness	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85
Circle	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Grain	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Rim-Core	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM
Adjacent	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.	FE-TI OX.
SiO ₂	33.32	34.44	34.61	34.28	35.32	35.32	34.39	34.39	34.39	34.39	34.12	35.42	35.37	35.76	35.37	35.76	35.76	35.76	35.76	35.76
TiO ₂	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Al ₂ O ₃	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cr ₂ O ₃	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
FeO	47.42	43.69	41.47	44.47	36.97	37.40	41.29	41.29	41.29	41.29	42.00	36.48	36.12	35.54	36.12	35.54	35.54	35.54	35.54	35.54
MnO	0.94	0.85	0.82	0.90	0.59	0.65	0.79	0.79	0.79	0.79	0.74	0.61	0.63	0.58	0.63	0.58	0.58	0.58	0.58	0.58
NiO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
MgO	18.04	21.02	22.59	20.40	25.89	25.66	22.70	22.70	22.70	22.70	22.13	26.40	26.33	27.68	26.33	27.68	27.68	27.68	27.68	27.68
BaO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CaO	0.32	0.30	0.36	0.31	0.31	0.33	0.35	0.35	0.35	0.35	0.32	0.33	0.29	0.30	0.29	0.30	0.30	0.30	0.30	0.30
Na ₂ O	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
K ₂ O	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Total	100.00	100.30	99.85	100.40	94.08	99.35	99.52	99.52	99.52	99.52	99.31	99.25	98.75	99.85	98.75	99.85	99.85	99.85	99.85	99.85
Fee	40.40	46.16	49.26	44.98	55.51	55.01	49.49	49.49	49.49	49.49	48.43	56.32	56.50	58.12	56.50	58.12	58.12	58.12	58.12	58.12

(Continued on next page)

Table A3.1

Sample	FELDSPAR ANALYSES					FELDSPAR ANALYSES					FELDSPAR ANALYSES				
	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07
Traverse	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Along Pos.	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173
Across Pos.	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15
Thickness	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5
Circle	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Grain	1.00	2.00	3.00	4.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Rim-Core	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Adjacent	--	FE-T1 OX.	--	--	--	--	--	--	--	--	--	--	--	--	--
SiO ₂	51.88	60.15	64.25	54.37	55.70	52.70	52.22	53.93	53.34	51.86	53.21	53.45	52.95	60.28	60.28
TiO ₂	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Al ₂ O ₃	30.27	24.69	22.09	29.21	28.06	30.23	30.67	29.68	30.05	31.05	30.15	30.18	30.20	24.91	24.91
Cr ₂ O ₃	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
FeO	0.42	0.39	0.31	0.40	0.71	0.39	0.40	0.35	0.39	0.37	0.43	0.39	0.43	0.35	0.35
MnO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
NiO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
MgO	0.00	0.40	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.30
BaO	12.77	6.16	3.21	11.32	10.22	12.69	13.37	12.02	12.34	13.90	12.80	12.58	12.34	6.55	6.55
CaO	4.23	7.32	8.79	4.80	5.32	4.28	4.02	4.47	4.37	3.70	4.14	4.33	4.29	7.01	7.01
Na ₂ O	0.29	0.80	1.11	0.31	0.43	0.27	0.22	0.28	0.30	0.20	0.24	0.26	0.27	1.11	1.11
K ₂ O	99.90	99.91	100.30	100.50	100.50	100.70	101.00	100.80	100.90	101.20	101.00	101.20	100.50	100.50	100.50
Total	61.48	30.26	15.71	55.56	50.20	61.14	63.95	58.80	59.89	66.72	62.20	60.70	60.42	31.86	31.86
Ave	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Sample	FELDSPAR ANALYSES					FELDSPAR ANALYSES					FELDSPAR ANALYSES				
	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07
Traverse	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Along Pos.	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173
Across Pos.	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15
Thickness	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5
Circle	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Grain	2.00	3.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Rim-Core	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Adjacent	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
SiO ₂	55.17	57.55	59.58	53.55	51.12	53.53	53.07	64.90	61.60	63.45	58.48	60.44	63.84	63.22	63.22
TiO ₂	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Al ₂ O ₃	28.44	26.30	24.99	28.91	30.40	29.31	29.32	22.61	24.46	22.00	26.04	25.09	21.55	22.37	22.37
Cr ₂ O ₃	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
FeO	0.46	0.43	0.36	--	--	--	--	--	--	--	0.34	0.32	0.18	0.21	0.21
MnO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
NiO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
MgO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
BaO	0.00	0.10	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.30	0.90	0.90	0.90
CaO	10.91	8.56	6.65	11.36	13.95	12.01	12.34	3.53	5.82	3.64	7.42	6.07	2.17	3.06	3.06
Na ₂ O	5.07	6.29	7.06	5.13	3.63	4.64	4.46	8.04	7.94	7.98	6.75	7.56	7.35	7.89	7.89
K ₂ O	0.38	0.57	1.10	0.36	0.37	0.36	0.36	2.08	0.67	3.68	0.80	0.79	4.07	2.53	2.53
Total	100.50	99.82	100.00	99.36	99.36	99.86	99.55	101.20	100.50	100.80	100.00	100.60	100.10	100.20	100.20
Ave	53.12	41.51	32.07	53.79	66.38	57.61	59.22	17.17	27.73	16.21	36.04	29.34	10.68	15.04	15.04

(Continued on next page)

Table A3.1

Sample	FELDSPAR ANALYSES				FELDSPAR ANALYSES				FELDSPAR ANALYSES			
	8203.11	8203.11	8401.07	8401.07	8401.07	8401.07	8401.07	8401.07	8401.07	8401.07	8401.07	8401.06
Traverse	5	5	7	7	7	7	7	7	7	7	7	7
Along Pos.	216	216	243	243	243	243	243	243	243	243	243	243
Across Pos.	-10.6	-10.6	-77.1	-77.1	-77.1	-77.1	-77.1	-77.1	-77.1	-77.1	-77.1	-77.1
Thickness	109	109	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5
Circles	4.00	4.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Grains	3.00	2.00	1.00	3.00	4.00	3.00	4.00	3.00	4.00	3.00	4.00	3.00
Rim-Core	--	--	--	--	--	--	--	--	--	--	--	--
Adjacent	--	--	--	--	--	--	--	--	--	--	--	--
SiO ₂	64.77	63.53	57.27	55.87	60.75	56.09	55.91	59.28	52.78	53.11	55.64	50.37
TiO ₂	--	--	--	--	--	--	--	--	--	--	--	--
Al ₂ O ₃	21.31	22.66	26.27	27.11	23.66	26.75	27.32	24.89	29.44	29.50	27.61	31.45
Cr ₂ O ₃	--	--	--	--	--	--	--	--	--	--	--	--
FeO†	0.20	0.21	0.13	0.25	0.23	0.23	0.27	0.28	0.24	0.25	0.30	0.32
MnO	--	--	--	--	--	--	--	--	--	--	--	--
NiO	--	--	--	--	--	--	--	--	--	--	--	--
MgO	--	--	--	--	--	--	--	--	--	--	--	--
NaO	0.60	0.90	0.20	0.10	0.10	0.10	0.10	0.30	0.00	0.00	0.00	0.00
CaO	1.93	3.04	8.06	9.06	5.24	8.88	9.43	6.39	11.86	11.77	9.55	13.84
Na ₂ O	7.80	8.06	6.88	6.08	7.66	6.25	5.83	7.48	4.58	4.56	5.73	3.64
K ₂ O	3.87	2.34	0.56	0.58	1.54	0.62	0.60	0.62	0.24	0.30	0.56	0.15
Total	100.50	100.80	99.36	99.09	99.23	99.00	99.49	99.32	99.20	99.57	99.46	99.81
Ann	9.35	14.89	38.06	43.66	25.03	42.43	45.57	30.92	58.04	57.76	46.39	67.17
												65.92

Sample	FELDSPAR ANALYSES				FELDSPAR ANALYSES				FELDSPAR ANALYSES			
	8401.06	8401.06	8401.06	8401.06	8401.06	8401.06	8401.06	8401.06	8401.06	8401.06	8401.06	8401.08
Traverse	7	7	7	7	7	7	7	7	7	7	7	7
Along Pos.	243	243	243	243	243	243	243	243	243	243	243	243
Across Pos.	-88.75	-88.75	-88.75	-88.75	-88.75	-88.75	-88.75	-88.75	-88.75	-88.75	-88.75	-71
Thickness	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5
Circles	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Grains	3.00	4.00	5.00	6.00	8.00	8.00	9.00	1.00	1.00	2.00	3.00	1.00
Rim-Core	--	--	--	--	--	--	--	--	--	--	--	--
Adjacent	--	--	--	--	--	--	--	--	--	--	--	--
SiO ₂	50.80	53.78	51.40	50.33	52.67	50.32	51.62	52.21	51.20	57.16	56.82	58.62
TiO ₂	--	--	--	--	--	--	--	--	--	--	--	--
Al ₂ O ₃	31.19	29.00	30.77	31.56	30.11	31.16	30.62	29.57	30.86	26.76	25.25	26.62
Cr ₂ O ₃	--	--	--	--	--	--	--	--	--	--	--	--
FeO†	0.28	0.20	0.31	0.24	0.28	0.34	0.31	0.31	0.32	0.33	0.26	0.39
MnO	--	--	--	--	--	--	--	--	--	--	--	--
NiO	--	--	--	--	--	--	--	--	--	--	--	--
MgO	--	--	--	--	--	--	--	--	--	--	--	--
NaO	0.00	0.10	0.00	0.10	0.10	0.00	0.00	0.00	0.00	0.10	0.20	0.10
CaO	13.55	10.79	13.10	13.65	12.31	13.73	13.02	11.51	12.81	8.03	7.72	8.17
Na ₂ O	3.65	5.70	4.07	3.71	4.56	3.62	3.96	4.62	4.33	6.34	6.97	6.65
K ₂ O	0.15	0.22	0.17	0.15	0.26	0.19	0.22	0.47	0.30	0.80	0.90	0.82
Total	99.68	99.79	99.91	99.74	100.30	99.41	99.79	98.78	99.86	99.57	98.18	99.01
Ann	56.64	50.50	63.39	66.45	58.98	66.95	63.67	56.34	60.99	39.26	36.07	39.51
												35.37

(Continued on next page)

Table A3.1

Sample	FELDSPAR ANALYSES										FELDSPAR ANALYSES									
	8401.08	8401.08	8401.08	8401.08	8401.08	8401.08	8401.08	8401.08	8401.08	8401.08	8401.08	8401.08	8401.08	8401.08	8401.08	8401.08	8401.08	8401.08	8401.08	8401.08
Traceable	7	243	243	243	243	243	243	243	243	243	7	243	243	243	243	243	243	243	243	243
Along Pos.	-71	-71	-71	-71	-71	-71	-71	-71	-71	-71	-71	-71	-71	-71	-71	-71	-71	-71	-71	-71
Across Pos.	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5
Thickness	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
Circles	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Grains	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Blm-Core	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Adjacent	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
SiO ₂	58.09	58.71	57.68	58.64	58.06	60.28	60.25	63.70	63.24	66.36	65.37	64.25	63.29	62.17	62.17	62.17	62.17	62.17	62.17	62.17
TiO ₂	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Al ₂ O ₃	25.38	25.67	25.72	25.40	25.22	24.06	23.74	21.44	21.07	19.04	19.85	19.54	21.13	21.62	21.62	21.62	21.62	21.62	21.62	21.62
Cr ₂ O ₃	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
FeO	0.36	0.45	0.29	0.36	0.32	0.28	0.26	0.22	0.17	0.25	0.13	0.14	0.18	0.21	0.21	0.21	0.21	0.21	0.21	0.21
MnO	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
NiO	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
NaO	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
K ₂ O	0.10	0.10	0.10	0.20	0.30	0.40	0.50	0.90	0.90	0.00	0.30	0.40	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Total	7.33	7.39	7.51	6.91	6.80	5.40	5.19	2.16	2.32	0.20	0.74	0.71	2.38	2.41	2.41	2.41	2.41	2.41	2.41	2.41
Ann	6.83	6.91	6.72	6.98	7.16	7.84	7.79	7.42	7.23	6.15	6.64	7.21	8.05	7.54	7.54	7.54	7.54	7.54	7.54	7.54
	0.81	0.58	0.57	0.77	0.56	0.90	1.17	3.80	4.02	7.46	6.35	5.54	3.77	3.62	3.62	3.62	3.62	3.62	3.62	3.62
	99.00	99.90	98.67	99.27	98.44	99.21	98.92	99.71	98.99	99.52	99.42	97.86	99.72	98.56	98.56	98.56	98.56	98.56	98.56	98.56
	35.49	35.90	36.91	33.78	33.30	26.14	25.10	10.74	11.49	0.99	3.64	3.49	11.10	11.83	11.83	11.83	11.83	11.83	11.83	11.83

Sample	FELDSPAR ANALYSES										FELDSPAR ANALYSES									
	8401.46	8401.46	8401.46	8401.46	8401.46	8401.46	8401.46	8401.46	8401.46	8401.46	8401.46	8401.46	8401.46	8401.46	8401.46	8401.46	8401.46	8401.46	8401.46	8401.46
Traceable	7	243	243	243	243	243	243	243	243	243	7	243	243	243	243	243	243	243	243	243
Along Pos.	104.7	104.7	104.7	104.7	104.7	104.7	104.7	104.7	104.7	104.7	104.7	104.7	104.7	104.7	104.7	104.7	104.7	104.7	104.7	104.7
Across Pos.	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5
Thickness	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Circles	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Grains	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Blm-Core	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Adjacent	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
SiO ₂	54.87	51.56	51.70	51.23	50.35	51.72	53.40	52.73	53.13	52.44	53.07	52.44	53.17	53.07	53.17	53.07	53.17	53.07	53.17	53.07
TiO ₂	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Al ₂ O ₃	28.49	30.59	30.87	30.71	31.44	30.49	28.86	29.89	29.85	29.96	29.50	29.70	29.45	29.53	29.45	29.53	29.45	29.53	29.45	29.53
Cr ₂ O ₃	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
FeO	0.59	0.54	0.59	1.11	0.58	0.65	0.83	0.63	0.55	0.65	0.56	0.58	0.59	0.60	0.59	0.60	0.59	0.60	0.59	0.60
MnO	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
NiO	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
NaO	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
K ₂ O	0.10	0.00	0.10	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	10.68	13.23	13.29	13.41	13.81	12.76	11.07	12.40	12.26	12.59	12.14	12.20	11.96	12.18	12.20	11.96	12.18	12.20	11.96	12.18
Ann	3.99	4.04	4.56	3.84	3.61	3.94	4.91	4.37	4.85	4.27	4.48	4.40	4.35	4.48	4.40	4.35	4.48	4.40	4.35	4.48
	0.32	0.23	0.19	0.15	0.18	0.20	0.32	0.30	0.34	0.28	0.42	0.31	0.38	0.36	0.31	0.38	0.36	0.31	0.38	0.36
	99.05	100.30	101.30	100.50	100.00	99.82	99.52	100.40	101.00	100.20	100.20	99.67	99.93	100.30	99.67	99.93	100.30	99.67	99.93	100.30
	58.42	63.56	61.05	65.30	67.18	63.39	54.44	60.00	57.18	60.97	58.51	59.42	58.96	58.80	58.51	59.42	58.96	58.80	58.51	58.80

(Continued on next page)

Table A3.1

Sample	FELDSPAR ANALYSES					FELDSPAR ANALYSES					FELDSPAR ANALYSES					FELDSPAR ANALYSES				
	8404.14	8404.14	8404.14	8404.14	8404.14	8201.04	8201.04	8201.04	8201.04	8201.04	8201.04	8201.04	8201.04	8201.04	8201.04	8201.04	8201.04	8201.04	8201.04	8201.04
Traverse	10	10	10	10	10	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
Along Pot.	330	330	330	330	330	337	337	337	337	337	337	337	337	337	337	337	337	337	337	337
Across Pot.	-93.075	-93.075	-93.075	-93.075	-93.075	-15.65	-15.65	-15.65	-15.65	-15.65	-15.65	-15.65	-15.65	-15.65	-15.65	-15.65	-15.65	-15.65	-15.65	-15.65
Thickness	186.55	186.55	186.55	186.55	186.55	160.5	160.5	160.5	160.5	160.5	160.5	160.5	160.5	160.5	160.5	160.5	160.5	160.5	160.5	160.5
Circle	2.00	2.00	2.00	2.00	2.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Grain	1.00	2.00	3.00	4.00	4.00	1.00	1.00	1.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Rim-Core	--	--	--	--	--	RIM	CORE	CORE	OLIVINE	--	--	--	--	--	--	--	--	--	--	--
Adjacent	--	--	--	--	--	58.89	58.00	63.27	63.36	63.75	64.13	65.86	65.86	66.58	67.04	67.04	67.04	67.04	67.04	67.04
SiO ₂	56.36	56.69	55.08	57.38	57.38	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TiO ₂	--	--	--	--	--	25.48	26.27	22.42	21.64	22.48	21.97	20.42	20.31	20.02	19.30	20.02	20.02	20.02	20.02	20.02
Al ₂ O ₃	27.51	27.30	27.65	26.88	26.88	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cr ₂ O ₃	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
FeO†	0.35	0.42	0.50	0.52	0.52	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
MnO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
NI†	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
NiO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
BaO	0.10	0.10	0.10	0.10	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CaO	9.69	9.36	9.94	8.74	8.74	7.67	8.69	3.38	3.43	3.31	3.07	1.94	1.29	1.14	0.36	1.14	1.29	1.14	0.36	0.36
Na ₂ O	5.98	5.39	5.69	6.16	6.16	6.72	6.20	8.06	7.79	8.29	8.04	8.41	6.94	7.05	7.67	7.05	6.94	7.05	7.67	7.67
K ₂ O	0.22	0.28	0.27	0.18	0.18	0.47	0.67	1.86	3.13	1.43	2.70	5.02	5.08	4.38	5.07	4.38	5.08	4.38	5.07	5.07
Total	100.30	99.56	99.25	99.97	99.97	99.23	99.83	98.98	99.36	99.25	99.93	101.60	99.48	99.17	99.44	99.17	99.48	99.17	99.44	99.44
Ann	46.65	48.13	48.35	43.48	43.48	37.62	41.97	16.75	16.14	16.54	14.74	8.39	6.48	5.96	1.78	5.96	6.48	5.96	1.78	1.78

Sample	FELDSPAR ANALYSES					FELDSPAR ANALYSES					FELDSPAR ANALYSES					FELDSPAR ANALYSES				
	8207.07	8207.07	8207.07	8207.07	8207.07	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18	8418.18
Traverse	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
Along Pot.	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427
Across Pot.	-3.5	-3.5	-3.5	-3.5	-3.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5
Thickness	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220
Circle	1.00	1.00	1.00	1.00	1.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Grain	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Rim-Core	RIM	CORE	CORE	CORE	CORE	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Adjacent	--	--	--	--	--	59.33	59.56	59.20	59.33	59.56	59.20	64.61	64.57	61.76	62.19	61.76	64.57	61.76	62.19	62.19
SiO ₂	53.74	54.23	54.37	56.96	56.96	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
TiO ₂	--	--	--	--	--	25.11	25.18	25.26	25.11	25.18	25.26	19.43	19.49	23.32	22.87	23.32	19.49	23.32	22.87	22.87
Al ₂ O ₃	29.17	28.61	28.41	26.83	26.83	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cr ₂ O ₃	--	--	--	--	--	0.25	0.29	0.26	0.20	0.21	0.26	0.08	0.08	0.19	0.18	0.19	0.08	0.19	0.18	0.18
FeO†	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
MnO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
NI†	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
NiO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
BaO	0.00	0.00	0.00	0.00	0.00	0.10	0.40	0.30	0.20	0.30	0.30	0.60	0.50	0.00	0.50	0.00	0.50	0.00	0.50	0.50
CaO	11.98	10.97	10.86	8.99	8.99	10.58	5.40	6.64	6.81	6.64	7.13	0.59	0.66	5.08	4.14	5.08	0.66	5.08	4.14	4.14
Na ₂ O	4.70	5.17	5.25	6.07	6.07	7.92	7.92	7.72	6.89	7.72	7.28	4.06	3.91	8.27	6.43	8.27	3.91	8.27	6.43	6.43
K ₂ O	0.33	0.47	0.44	0.58	0.58	0.33	0.93	0.69	0.86	0.69	0.72	10.37	9.87	0.69	1.19	0.69	9.87	0.69	1.19	1.19
Total	99.92	99.45	99.32	99.43	99.43	100.80	99.84	100.30	99.45	100.30	100.10	99.79	99.17	99.36	99.58	99.36	99.17	99.36	99.58	99.58
Ann	57.38	52.53	52.00	43.50	43.50	47.52	25.91	30.98	33.54	30.98	33.69	2.91	3.39	24.35	17.89	24.35	3.39	24.35	17.89	17.89

(Continued on next page)

Table A3.1

Sample	FELDSPAR ANALYSES					FELDSPAR ANALYSES					FELDSPAR ANALYSES					FELDSPAR ANALYSES				
	8418.18	8418.18	8418.18	8418.18	8418.18	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15	8418.15
Traverse	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
Along.Fos.	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427
Across.Fos.	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5
Thickness	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220
Chlorine	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
Grains	4.00	5.00	6.00	7.00	8.00	1.00	2.00	3.00	4.00	1.00	2.00	3.00	4.00	1.00	2.00	3.00	4.00	1.00	2.00	3.00
Blm.Core	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Adjacent	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
SiO ₂	62.51	62.66	57.75	55.62	57.53	63.07	64.09	58.25	62.26	62.36	58.01	62.83	59.11	58.54	62.83	59.11	58.54	62.83	59.11	58.54
TiO ₂	22.90	22.89	25.96	27.60	26.11	23.25	22.44	26.01	22.90	23.09	26.10	23.32	25.13	25.92	23.32	25.13	25.92	23.32	25.13	25.92
Al ₂ O ₃	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cr ₂ O ₃	0.23	0.24	0.26	0.28	0.18	0.19	0.14	0.21	0.14	0.24	0.32	0.13	0.29	0.27	0.32	0.13	0.29	0.27	0.32	0.27
FeO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
MnO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
NiO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
MgO	0.00	0.10	0.20	0.10	0.20	0.30	0.20	0.20	0.10	0.60	0.20	0.10	0.30	0.20	0.60	0.20	0.10	0.30	0.20	0.20
CaO	3.91	4.19	7.63	9.69	8.11	3.58	2.90	6.85	3.69	3.78	7.49	3.41	6.24	7.07	3.78	7.49	3.41	6.24	7.07	7.07
Na ₂ O	8.60	8.41	6.73	5.68	6.33	7.25	7.67	6.09	7.68	6.89	5.56	7.43	6.01	5.80	6.89	5.56	7.43	6.01	5.80	5.80
K ₂ O	1.85	1.22	0.66	0.39	0.46	2.13	1.41	0.60	0.97	2.12	0.85	0.59	0.78	0.88	2.12	0.85	0.59	0.78	0.88	0.88
Total	99.57	99.73	99.22	99.36	98.92	99.76	98.94	98.27	97.77	99.18	98.58	97.85	97.87	98.72	99.18	98.58	97.85	97.87	98.72	98.72
Ave	18.04	20.09	37.05	47.42	40.32	18.61	15.71	36.86	19.69	20.14	40.35	19.42	34.58	37.98	20.14	40.35	19.42	34.58	37.98	37.98

Sample	FELDSPAR ANALYSES					FELDSPAR ANALYSES					FELDSPAR ANALYSES					FELDSPAR ANALYSES				
	8418.15	8418.15	8418.15	8418.15	8418.15	8208.06	8208.06	8208.06	8208.06	8208.06	8208.04	8208.04	8208.04	8208.04	8208.04	8208.04	8208.04	8208.04	8208.04	8208.04
Traverse	14	14	14	14	14	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Along.Fos.	427	427	427	427	427	614	614	614	614	614	614	614	614	614	614	614	614	614	614	614
Across.Fos.	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5
Thickness	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220
Chlorine	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00	300.00
Grains	2.00	3.00	4.00	5.00	6.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Blm.Core	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Adjacent	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
SiO ₂	62.59	63.26	60.64	55.71	56.75	58.88	58.64	54.17	62.30	63.90	53.99	55.17	59.59	61.39	53.99	55.17	59.59	61.39	61.39	61.39
TiO ₂	23.26	22.63	24.53	27.14	26.12	25.35	25.34	28.64	22.82	22.24	28.64	27.96	25.03	23.62	28.64	27.96	25.03	23.62	23.62	23.62
Al ₂ O ₃	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Cr ₂ O ₃	0.10	0.48	0.29	--	--	--	--	0.32	0.14	0.15	0.24	0.44	0.15	0.14	0.24	0.44	0.15	0.14	0.14	0.14
FeO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
MnO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
NiO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
MgO	0.90	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.70	0.30	0.10	0.00	0.30	0.20	0.10	0.00	0.30	0.20	0.20	0.20
CaO	3.93	3.05	5.32	9.94	8.61	7.51	11.32	10.92	3.83	3.21	11.04	10.05	6.32	4.95	11.04	10.05	6.32	4.95	4.95	4.95
Na ₂ O	6.36	5.99	6.37	5.97	6.72	6.53	5.49	5.20	8.45	8.78	5.14	5.59	7.71	8.57	5.14	5.59	7.71	8.57	8.57	8.57
K ₂ O	0.73	3.77	1.29	0.42	0.42	0.68	0.20	0.29	1.18	1.50	0.29	0.52	0.41	0.65	0.29	0.52	0.41	0.65	0.65	0.65
Total	97.92	99.75	98.95	99.20	98.62	98.95	101.00	99.62	99.43	100.10	99.37	99.81	99.55	99.54	99.37	99.81	99.55	99.54	99.54	99.54
Ave	24.10	16.60	29.94	46.71	40.48	37.30	52.67	52.82	18.66	15.37	53.37	48.35	30.44	23.31	53.37	48.35	30.44	23.31	23.31	23.31

Table A3.1

Sample#	FELDSPAR ANALYSES				FELDSPAR ANALYSES				FELDSPAR ANALYSES				FELDSPAR ANALYSES			
	R208.04	R208.04	R208.04	R208.04	R208.08	R208.08	R208.08	R208.08	R208.08	R208.08	R208.08	R208.08	R209.02	R209.02	R209.02	R209.02
Traverse	15	15	15	15	15	15	15	15	15	15	15	15	16	16	16	16
Along Pos.	614	614	614	614	614	614	614	614	614	614	614	614	702	702	702	702
Across Pos.	13	13	13	13	13	13	13	13	13	13	13	13	1	1	1	1
Thickness	148	148	148	148	148	148	148	148	148	148	148	148	85	85	85	85
Circles	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	200.00	200.00	200.00	200.00
Grains	5.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	1.00	1.00	1.00	1.00
Rim-Core	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Adjacent	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
SiO ₂	59.04	64.68	51.52	53.42	51.47	52.10	56.60	56.39	55.98	54.77	52.77	59.57	54.71	54.71	56.36	56.36
TiO ₂	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Al ₂ O ₃	24.65	19.32	31.30	29.13	31.04	30.23	27.41	27.16	28.06	28.23	29.44	24.68	28.28	28.28	26.99	26.99
Cr ₂ O ₃	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
FeO†	0.22	0.11	0.33	0.36	0.29	0.46	0.52	0.50	0.42	0.40	0.43	0.30	0.33	0.33	0.39	0.39
MnO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
NiO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
MgO	0.40	0.20	0.00	0.00	0.00	0.00	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
CaO	6.29	0.57	13.07	11.30	13.25	12.31	8.92	8.83	9.80	10.40	11.60	5.82	10.20	10.20	8.70	8.70
Na ₂ O	7.39	3.71	3.57	4.55	3.54	3.99	5.45	5.45	4.86	5.95	4.63	7.31	5.37	5.37	6.00	6.00
K ₂ O	0.77	10.18	0.19	0.30	0.21	0.23	0.60	0.61	0.49	0.35	0.33	0.95	0.42	0.42	0.58	0.58
Total	99.56	98.82	100.00	99.09	99.81	99.33	99.60	99.06	99.71	100.30	99.28	99.03	99.40	99.40	98.14	98.14
Ann	30.56	2.94	66.16	50.81	60.56	62.16	45.75	45.47	51.10	48.18	56.94	28.64	49.96	49.96	42.37	42.37

Sample#	FELDSPAR ANALYSES				FELDSPAR ANALYSES				FELDSPAR ANALYSES				FELDSPAR ANALYSES			
	R209.02	R209.02	R209.02	R209.02	R209.02	R209.02	R209.02	R209.02	R209.02	R209.02	R209.02	R209.02	R209.02	R209.02	R209.02	R209.02
Traverse	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16
Along Pos.	702	702	702	702	702	702	702	702	702	702	702	702	702	702	702	702
Across Pos.	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Thickness	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85
Circles	200.00	200.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Grains	2.00	3.00	1.00	2.00	3.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Rim-Core	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Adjacent	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
SiO ₂	59.13	53.27	55.97	56.71	58.37	61.58	60.83	56.46	56.46	56.46	56.46	56.46	56.46	56.46	56.46	56.46
TiO ₂	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Al ₂ O ₃	25.48	29.43	27.48	27.07	25.91	23.22	23.98	26.66	26.66	26.66	26.66	26.66	26.66	26.66	26.66	26.66
Cr ₂ O ₃	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
FeO†	0.34	0.42	0.41	0.45	0.56	0.42	0.29	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67
MnO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
NiO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
MgO	0.40	0.00	0.10	0.10	0.20	0.50	0.50	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
CaO	6.84	11.56	9.60	8.77	7.43	4.71	5.24	8.59	8.59	8.59	8.59	8.59	8.59	8.59	8.59	8.59
Na ₂ O	7.28	4.58	5.87	6.06	6.84	7.64	7.74	6.32	6.32	6.32	6.32	6.32	6.32	6.32	6.32	6.32
K ₂ O	0.78	0.34	0.46	0.41	0.66	2.03	1.11	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Total	100.30	99.62	99.88	99.62	100.00	99.65	99.75	99.22	99.22	99.22	99.22	99.22	99.22	99.22	99.22	99.22
Ann	32.66	57.08	46.22	43.36	36.08	20.58	25.48	42.02	42.02	42.02	42.02	42.02	42.02	42.02	42.02	42.02

(Continued on next page)

Table A3.1

CLINOPYROXENE ANALYSES									
Sample	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07
Transverse	2	2	2	2	2	2	2	2	2
Along Pos.	173	173	173	173	173	173	173	173	173
Across Pos.	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15	17.15
Thickness	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5
Circle	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Grain	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Rim-Core	---	---	---	---	---	---	---	---	---
Adjacent	---	---	---	---	---	---	---	---	---
SiO ₂	50.93	50.69	51.06	50.21	50.43	50.17	51.23	50.27	50.85
TiO ₂	1.17	1.25	1.13	1.44	1.42	1.59	1.13	1.48	1.21
Al ₂ O ₃	2.19	2.29	2.03	2.81	2.66	3.21	2.09	2.50	2.16
Cr ₂ O ₃	---	---	---	---	---	---	---	0.00	0.00
FeO ¹	12.64	12.64	12.89	10.74	10.80	11.26	10.81	11.23	10.88
MnO	0.32	0.26	0.32	0.21	0.23	0.24	0.24	0.25	0.25
MgO	---	---	---	---	---	---	---	---	---
NaO	12.09	12.19	11.90	13.03	12.95	12.64	13.41	13.06	13.31
BeO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CaO	20.52	20.29	20.21	20.45	20.35	20.32	20.32	20.20	20.51
Na ₂ O	0.47	0.43	0.49	0.47	0.44	0.46	0.40	0.55	0.52
K ₂ O	---	---	---	---	---	---	---	---	---
Total	100.30	100.00	100.00	99.37	99.27	99.88	99.62	99.51	99.69
Err	63.02	63.22	62.19	68.37	68.12	66.67	68.85	67.26	67.37
CLINOPYROXENE ANALYSES									
Sample	8203.11	8401.55	8401.55	8401.55	8401.55	8401.55	8401.55	8401.55	8401.55
Transverse	5	7	7	7	7	7	7	7	7
Along Pos.	216	243	243	243	243	243	243	243	243
Across Pos.	-10.6	89.75	89.75	89.75	89.75	89.75	89.75	89.75	89.75
Thickness	109	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5
Circle	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Grain	2.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Rim-Core	---	---	---	---	---	---	---	---	---
Adjacent	---	---	---	---	---	---	---	---	---
SiO ₂	50.57	51.22	51.89	52.61	52.46	49.21	49.24	49.76	49.73
TiO ₂	0.06	1.38	1.00	0.87	0.98	2.38	2.11	1.85	1.91
Al ₂ O ₃	1.38	2.39	2.02	1.76	2.02	4.28	4.09	3.44	3.45
Cr ₂ O ₃	1.09	0.00	0.01	0.02	0.00	0.03	0.01	0.03	0.01
FeO ¹	15.03	10.35	10.24	9.21	9.22	10.23	10.33	10.27	10.24
MnO	0.31	0.25	0.23	0.23	0.18	0.21	0.26	0.27	0.24
MgO	---	---	---	---	---	---	---	---	---
NaO	11.47	13.16	13.55	13.66	13.68	12.96	12.62	12.82	13.01
BeO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CaO	20.49	20.71	20.26	21.36	21.40	20.17	20.21	20.85	21.05
Na ₂ O	0.06	0.48	0.60	0.49	0.56	0.57	0.51	0.42	0.45
K ₂ O	---	---	---	---	---	---	---	---	---
Total	100.50	99.94	99.80	100.20	100.50	100.00	99.39	99.76	100.10
Err	57.63	69.38	70.22	72.55	72.56	69.30	68.22	64.69	69.99

CLINOPYROXENE ANALYSES									
Sample	8203.11	8203.13	8203.13	8203.13	8203.13	8203.13	8203.13	8203.13	8203.13
Transverse	5	5	5	5	5	5	5	5	5
Along Pos.	216	216	216	216	216	216	216	216	216
Across Pos.	-10.6	-34.35	-34.35	-34.35	-34.35	-34.35	-34.35	-34.35	-34.35
Thickness	109	109	109	109	109	109	109	109	109
Circle	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Grain	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Rim-Core	---	---	---	---	---	---	---	---	---
Adjacent	---	---	---	---	---	---	---	---	---
SiO ₂	50.66	49.99	50.85	50.27	50.15	50.27	50.85	49.99	50.66
TiO ₂	0.49	1.55	1.21	1.51	1.48	1.51	1.21	1.55	0.49
Al ₂ O ₃	0.62	2.64	2.16	2.57	2.50	2.57	2.16	2.64	0.62
Cr ₂ O ₃	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
FeO ¹	15.16	11.26	10.88	11.23	11.33	11.23	10.88	11.26	15.16
MnO	0.35	0.26	0.25	0.25	0.25	0.25	0.25	0.26	0.35
MgO	---	---	---	---	---	---	---	---	---
NaO	10.37	13.10	13.31	13.01	13.06	13.01	13.31	13.10	10.37
BeO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CaO	21.05	20.44	20.51	20.25	20.20	20.25	20.51	20.44	21.05
Na ₂ O	0.57	0.54	0.52	0.50	0.55	0.50	0.52	0.54	0.57
K ₂ O	---	---	---	---	---	---	---	---	---
Total	100.10	99.77	99.69	99.57	99.51	99.57	99.69	99.77	100.10
Err	53.52	67.46	68.55	67.37	67.26	67.37	68.55	67.46	53.52

CLINOPYROXENE ANALYSES									
Sample	8401.06	8401.06	8401.06	8401.06	8401.06	8401.06	8401.06	8401.06	8401.06
Transverse	7	7	7	7	7	7	7	7	7
Along Pos.	243	243	243	243	243	243	243	243	243
Across Pos.	-88.75	-88.75	-88.75	-88.75	-88.75	-88.75	-88.75	-88.75	-88.75
Thickness	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5	209.5
Circle	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Grain	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Rim-Core	---	---	---	---	---	---	---	---	---
Adjacent	---	---	---	---	---	---	---	---	---
SiO ₂	49.73	49.73	49.73	49.76	49.73	49.76	49.73	49.73	49.73
TiO ₂	1.70	2.02	1.91	1.85	1.74	1.85	1.91	2.02	1.70
Al ₂ O ₃	3.19	3.41	3.45	3.44	1.88	3.44	3.45	3.41	3.19
Cr ₂ O ₃	0.02	0.02	0.01	0.03	0.04	0.03	0.01	0.02	0.02
FeO ¹	10.24	10.35	10.24	10.27	12.06	10.27	10.24	10.35	10.24
MnO	0.31	0.30	0.27	0.27	0.34	0.27	0.27	0.30	0.31
MgO	---	---	---	---	---	---	---	---	---
NaO	13.22	13.14	13.01	12.82	12.40	12.82	13.01	13.14	13.22
BeO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CaO	21.11	21.18	21.05	20.85	20.83	20.85	21.05	21.18	21.11
Na ₂ O	0.40	0.45	0.45	0.48	0.42	0.48	0.45	0.45	0.40
K ₂ O	---	---	---	---	---	---	---	---	---
Total	99.95	100.30	100.10	99.76	100.10	99.76	100.10	100.30	99.95
Err	60.73	69.70	69.36	69.99	64.69	69.99	69.36	69.70	60.73

(Continued on next page)

Table A3.1

Sample	CLINOPYROXENE ANALYSES												CLINOPYROXENE ANALYSES												CLINOPYROXENE ANALYSES												CLINOPYROXENE ANALYSES																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																											
	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13	8401.13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Table A3.1

CLINOPYROXENE ANALYSES									
Sample	8401.08	8401.08	8401.08	8404.14	8404.14	8404.14	8404.14	8404.14	8404.14
Transverse	7	7	7	10	10	10	10	10	10
Along Pos.	243	243	243	330	330	330	330	330	330
Across Pos.	-71	-71	-71	-93.075	-93.075	-93.075	-93.075	-93.075	-93.075
Thickness	209.5	209.5	209.5	186.55	186.55	186.55	186.55	186.55	186.55
Circle	4.00	4.00	4.00	3.00	3.00	3.00	3.00	3.00	3.00
Grain	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Rim-Core	RIM	RIM	RIM	INTERM.	INTERM.	INTERM.	INTERM.	INTERM.	INTERM.
Adjacent	FELDSPAR	FELDSPAR	FELDSPAR	OLIVINE	OLIVINE	OLIVINE	OLIVINE	OLIVINE	OLIVINE
SiO ₂	50.19	50.25	50.24	49.29	49.48	50.09	50.64	51.46	51.01
TiO ₂	1.31	0.93	0.52	1.85	1.78	1.80	1.48	1.16	1.11
Al ₂ O ₃	2.13	1.27	1.02	3.83	3.76	3.84	2.27	3.16	1.99
Cr ₂ O ₃	13.72	16.28	16.15	10.10	9.73	9.98	9.51	9.63	13.39
FeO ¹	0.34	0.46	0.33	0.18	0.25	0.20	0.22	0.22	0.33
MnO	11.27	9.31	8.80	13.37	13.40	13.88	14.81	13.97	11.56
MgO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CaO	20.33	20.55	21.15	20.42	20.40	20.15	20.32	19.52	20.54
Na ₂ O	0.50	0.42	0.52	0.45	0.48	0.44	0.40	0.42	0.39
K ₂ O	99.78	99.47	98.72	99.50	99.26	100.40	99.65	99.54	100.10
Total	59.41	50.47	49.26	70.23	71.05	71.25	73.51	72.11	60.61
Err									
CLINOPYROXENE ANALYSES									
Sample	8201.03	8201.03	8201.03	8207.07	8207.07	8207.07	8207.07	8207.07	8207.07
Transverse	11	11	11	14	14	14	14	14	14
Along Pos.	337	337	337	427	427	427	427	427	427
Across Pos.	32.75	32.75	32.75	-3.5	-3.5	-3.5	-3.5	-3.5	-3.5
Thickness	160.5	160.5	160.5	220	220	220	220	220	220
Circle	6.00	9.00	9.00	2.00	2.00	2.00	2.00	2.00	2.00
Grain	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Rim-Core	INTERM.	INTERM.	INTERM.	RIM	RIM	RIM	RIM	RIM	RIM
Adjacent	FE-TI OX.	FE-TI OX.	FE-TI OX.	CORE	CORE	CORE	CORE	CORE	CORE
SiO ₂	50.97	51.07	51.31	50.71	50.69	50.83	50.66	50.78	50.48
TiO ₂	0.88	0.76	0.99	0.90	1.33	1.01	0.98	1.00	1.21
Al ₂ O ₃	1.55	1.29	1.51	1.49	2.31	1.68	1.90	1.57	2.31
Cr ₂ O ₃	0.01	0.02	0.03	0.00	0.00	0.01	0.00	0.00	0.00
FeO ¹	14.02	14.85	13.40	15.33	11.20	14.71	13.66	14.32	11.43
MnO	0.38	0.48	0.38	0.38	0.29	0.39	0.34	0.36	0.29
NiO	11.42	10.49	12.06	10.64	12.99	10.77	11.83	11.23	12.85
MgO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CaO	20.45	20.56	16.86	20.11	20.84	20.24	20.43	20.55	20.50
Na ₂ O	0.38	0.32	0.27	0.40	0.49	0.46	0.49	0.47	0.44
K ₂ O	100.10	99.84	99.80	100.10	100.10	100.10	100.30	100.30	99.50
Total	53.21	55.73	61.59	55.29	67.39	56.61	60.68	58.29	66.70
Err									

(Continued on next page)

Table A3.1

CLINOPYROXENE ANALYSES									
Sample	8418.18	8418.18	8418.18	8418.18	8208.06	8208.06	8208.06	8209.02	8209.02
Transverse	14	14	14	14	15	15	16	16	16
Along Pen.	427	427	427	427	614	614	702	702	702
Across Pen.	15.5	15.5	15.5	15.5	-30.65	-30.65	1	1	1
Thickness	220	220	220	220	148	148	85	85	85
Circle	5.00	5.00	5.00	5.00	2.00	2.00	300.00	300.00	400.00
Grain	1.00	1.00	1.00	1.00	2.00	2.00	1.00	2.00	1.00
Rim-Core	CORE	RIM	INTERM.	RIM	CORE	CORE	CORE	CORE	CORE
Adjacent	OLIVINE	FE-TI	OX. FELDSPAR						FE-TI OX.
SiO ₂	51.14	50.96	50.99	51.05	50.37	50.06	49.76	49.77	47.82
TiO ₂	1.14	1.28	1.31	1.08	1.67	1.74	1.60	1.79	1.70
Al ₂ O ₃	2.09	2.51	2.52	1.96	2.54	2.87	3.27	3.52	3.47
Cr ₂ O ₃	--	--	--	--	0.02	0.01	--	--	--
FeO	11.94	11.73	11.97	13.28	11.37	11.46	10.50	10.50	10.60
MnO	0.27	0.29	0.28	0.37	0.22	0.22	0.27	0.24	0.24
NiO	--	--	--	--	--	--	--	--	--
NaO	12.32	12.24	12.12	11.25	12.88	12.75	13.44	12.89	13.02
BaO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CaO	20.74	20.77	20.75	20.94	20.77	20.75	20.36	20.63	20.29
MgO	0.42	0.42	0.42	0.41	0.53	0.51	0.41	0.42	0.42
K ₂ O	--	--	--	--	--	--	--	--	--
Total	100.10	100.20	100.40	100.30	100.40	100.40	99.57	100.10	99.57
Fe	64.77	65.03	64.34	60.15	66.07	66.47	69.66	68.63	68.64
									65.15

CLINOPYROXENE ANALYSES									
Sample	8209.02	8209.02	8209.02	8209.02	8208.06	8208.06	8208.06	8209.02	8209.02
Transverse	16	16	16	16	15	15	16	16	16
Along Pen.	702	702	702	702	614	614	702	702	702
Across Pen.	1	1	1	1	-30.65	-30.65	1	1	1
Thickness	85	85	85	85	148	148	85	85	85
Circle	400.00	400.00	400.00	400.00	2.00	2.00	300.00	300.00	400.00
Grain	1.00	1.00	1.00	1.00	2.00	2.00	1.00	2.00	1.00
Rim-Core	RIM	RIM	CORE	CORE	CORE	CORE	CORE	CORE	CORE
Adjacent	FF-TI	OX. FELDSPAR							FE-TI OX.
SiO ₂	50.19	50.56	49.85		50.37	50.06	49.76	49.77	47.82
TiO ₂	1.45	1.42	1.67		1.67	1.74	1.60	1.79	1.70
Al ₂ O ₃	3.11	2.81	3.54		2.54	2.87	3.27	3.52	3.47
Cr ₂ O ₃	--	--	--		0.02	0.01	--	--	--
FeO	10.51	10.49	10.29		11.37	11.46	10.50	10.50	10.60
MnO	0.27	0.23	0.24		0.22	0.22	0.27	0.24	0.24
NiO	--	--	--		--	--	--	--	--
NaO	13.15	13.09	13.16		12.88	12.75	13.44	12.89	13.02
BaO	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00
CaO	20.46	20.53	20.35		20.77	20.75	20.36	20.63	20.29
MgO	0.44	0.43	0.45		0.53	0.51	0.41	0.42	0.42
K ₂ O	--	--	--		--	--	--	--	--
Total	99.18	99.56	99.54		100.40	100.40	99.57	100.10	99.57
Fe	69.04	68.98	68.70		66.07	66.47	69.66	68.63	68.64
									65.15

Table A3.1

TITANOMAGNETITE ANALYSES									
Sample	8428.03	8428.03	8428.03	8428.03	8428.03	8428.07	8428.07	8428.07	8428.07
Traverse	2	2	2	2	2	2	2	2	2
Along Pen.	173	173	173	173	173	173	173	173	173
Across Pen.	-25.3	-25.3	-25.3	-25.3	-25.3	17.15	17.15	17.15	17.15
Thickness	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5
Circle	100.00	100.00	100.00	200.00	200.00	200.00	200.00	200.00	100.00
Grain	1.00	2.00	3.00	1.00	2.00	1.00	3.00	1.00	2.00
Rim:Core	--	--	--	--	--	--	--	--	--
Adjacent	--	--	--	--	--	--	--	--	--
SiO ₂	--	--	--	--	--	--	--	--	--
TiO ₂	17.63	17.38	15.66	19.18	17.65	16.42	17.61	17.49	19.04
Al ₂ O ₃	2.44	2.46	2.81	2.04	2.31	2.07	1.99	1.99	1.51
Cr ₂ O ₃	--	--	--	--	--	--	--	--	--
FeO	73.89	74.44	75.68	73.46	74.62	75.40	74.96	74.54	73.78
MnO	0.71	0.62	0.69	0.64	0.61	0.68	0.63	0.64	0.71
NiO	--	--	--	--	--	--	--	--	--
MgO	0.36	0.35	0.26	0.45	0.41	0.18	0.21	0.25	0.23
BaO	--	--	--	--	--	--	--	--	--
CaO	--	--	--	--	--	--	--	--	--
Na ₂ O	--	--	--	--	--	--	--	--	--
K ₂ O	--	--	--	--	--	--	--	--	--
Total	95.02	95.25	95.10	95.78	95.59	94.75	95.40	94.98	95.27
Unsp	50.31	49.47	44.52	54.45	50.07	47.08	50.21	50.07	54.55
TITANOMAGNETITE ANALYSES									
Sample	8203.11	8203.11	8203.11	8203.11	8203.11	8401.24	8401.24	8401.24	8401.24
Traverse	5	5	5	5	5	7	7	7	7
Along Pen.	216	216	216	216	216	243	243	243	243
Across Pen.	-10.6	-10.6	-10.6	-10.6	-10.6	78.5	78.5	78.5	78.5
Thickness	109	109	109	109	109	209.5	209.5	209.5	220
Circle	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	200.00
Grain	1.00	2.00	3.00	4.00	5.00	1.00	2.00	3.00	4.00
Rim:Core	--	--	--	--	--	--	--	--	--
Adjacent	--	--	--	--	--	--	--	--	--
SiO ₂	--	--	--	--	--	--	--	--	--
TiO ₂	12.71	14.32	14.19	17.44	14.48	15.52	13.15	12.88	13.51
Al ₂ O ₃	1.05	0.68	0.69	0.78	0.87	2.15	2.30	2.42	2.42
Cr ₂ O ₃	--	--	--	--	--	--	--	--	--
FeO	79.44	78.19	78.54	75.00	77.82	76.65	78.41	78.74	78.08
MnO	0.57	0.45	0.45	0.68	0.53	0.54	0.43	0.52	0.43
NiO	--	--	--	--	--	--	--	--	--
MgO	0.08	0.11	0.14	0.09	0.13	0.47	0.16	0.19	0.23
BaO	--	--	--	--	--	--	--	--	--
CaO	--	--	--	--	--	--	--	--	--
Na ₂ O	--	--	--	--	--	--	--	--	--
K ₂ O	--	--	--	--	--	--	--	--	--
Total	93.85	93.76	94.02	93.99	93.83	95.34	94.44	94.75	96.69
Unsp	36.84	41.68	41.17	50.79	47.08	44.06	37.66	36.73	60.72

TITANOMAGNETITE ANALYSES									
Sample	8203.13	8203.13	8203.13	8203.13	8203.13	8418.15	8418.15	8418.15	8418.15
Traverse	5	5	5	5	5	14	14	14	14
Along Pen.	216	216	216	216	216	427	427	427	427
Across Pen.	-34.35	-34.35	-34.35	-34.35	-34.35	-52.5	-52.5	-52.5	-52.5
Thickness	109	109	109	109	109	220	220	220	220
Circle	100.00	100.00	100.00	100.00	100.00	200.00	200.00	200.00	200.00
Grain	1.00	2.00	3.00	1.00	2.00	2.00	3.00	1.00	2.00
Rim:Core	--	--	--	--	--	--	--	--	--
Adjacent	--	--	--	--	--	--	--	--	--
SiO ₂	--	--	--	--	--	--	--	--	--
TiO ₂	9.70	11.44	12.41	11.19	11.19	22.66	25.68	14.33	17.08
Al ₂ O ₃	4.53	3.75	3.74	3.76	3.76	1.69	1.33	1.85	2.03
Cr ₂ O ₃	--	--	--	--	--	--	--	--	--
FeO	78.97	78.02	77.64	78.44	78.44	70.97	58.08	76.54	76.12
MnO	0.35	0.41	0.47	0.41	0.41	0.95	0.78	0.67	0.60
NiO	--	--	--	--	--	--	--	--	--
MgO	0.50	0.47	0.61	0.64	0.64	0.16	0.23	0.19	0.17
BaO	--	--	--	--	--	--	--	--	--
CaO	--	--	--	--	--	--	--	--	--
Na ₂ O	--	--	--	--	--	--	--	--	--
K ₂ O	--	--	--	--	--	--	--	--	--
Total	94.06	94.10	94.85	94.45	94.45	96.44	96.10	93.58	96.08
Unsp	27.45	32.54	35.01	31.66	31.66	64.36	73.51	41.55	48.34

Table A3.1

Sample	TITANUMAGNETITE ANALYSES				TITANUMAGNETITE ANALYSES			
	8418.18	8418.16	8418.16	8418.16	8418.03	8418.03	8209.04	8209.04
Trace	14	14	14	14	14	14	16	16
Along Pos.	427	427	427	427	427	427	702	702
Across Pos.	15.5	-21.5	-21.5	-21.5	-78.65	-78.65	17.35	17.35
Thickness	220	220	220	220	220	220	85	85
Circles	200.00	100.00	100.00	200.00	200.00	200.00	100.00	100.00
Grain	3.00	1.00	1.00	2.00	2.00	3.00	2.00	3.00
Rim-Core	--	--	--	--	--	--	--	--
Adjacent	--	--	--	--	--	--	--	--
SiO ₂	--	--	--	--	--	--	--	--
TiO ₂	16.47	14.56	11.28	13.44	20.92	21.33	20.30	20.02
Al ₂ O ₃	1.97	1.92	2.00	1.76	1.73	2.10	1.96	1.79
Cr ₂ O ₃	--	--	--	--	--	--	--	--
FeO _T	76.39	78.16	80.70	78.13	72.45	70.30	71.91	69.49
MnO	0.65	0.68	0.62	0.79	0.70	0.71	0.63	0.68
NO	--	--	--	--	--	--	--	--
MgO	0.12	0.11	0.05	0.04	0.54	0.45	0.85	0.96
BaO	--	--	--	--	--	--	--	--
CaO	--	--	--	--	--	--	--	--
Na ₂ O	--	--	--	--	--	--	--	--
K ₂ O	--	--	--	--	--	--	--	--
Total	95.60	95.42	94.64	94.16	96.35	94.90	95.64	94.58
Usp	46.84	41.41	37.24	38.75	59.18	61.74	57.60	57.68

(Continued on next page)

Table A3.1

Sample	OLIVINE ANALYSES					OLIVINE ANALYSES					OLIVINE ANALYSES					OLIVINE ANALYSES				
	8208.06	8208.06	8208.06	8208.06	8208.06	8208.04	8208.04	8208.04	8208.04	8208.04	8208.08	8208.08	8208.08	8208.08	8208.08	8208.05	8208.05	8208.05	8208.05	8208.05
Traverse	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Along.Fen.	614	614	614	614	614	614	614	614	614	614	614	614	614	614	614	614	614	614	614	614
Across.Fen.	-30.65	-30.65	-30.65	-30.65	-30.65	13	13	13	13	13	13	13	13	13	13	-15.35	-15.35	-15.35	-15.35	-15.35
Thickness	148	148	148	148	148	148	148	148	148	148	148	148	148	148	148	148	148	148	148	148
Circles	3.00	3.00	3.00	3.00	3.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Grains	2.00	2.00	2.00	2.00	2.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Rim-Core	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM
Adjacent	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
SiO ₂	34.15	34.78	33.63	32.93	34.95	33.90	35.29	35.29	35.29	35.29	35.29	35.29	35.29	35.29	35.29	34.00	33.77	33.57	33.55	33.44
TiO ₂	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Al ₂ O ₃	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Cr ₂ O ₃	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
FeO	40.70	40.56	46.87	47.34	39.74	43.18	37.99	37.99	37.99	37.99	37.99	37.99	37.99	37.99	37.99	44.77	47.80	47.33	47.63	46.79
MnO	0.75	0.71	0.96	1.03	0.65	0.79	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.90	1.06	0.96	0.98	0.98
NiO	0.00	0.00	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
MgO	23.34	24.17	18.39	18.08	24.14	20.17	25.41	25.41	25.41	25.41	25.41	25.41	25.41	25.41	25.41	19.56	17.48	18.10	17.63	17.92
NaO	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
CaO	0.35	0.38	0.38	0.37	0.31	0.34	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.39	0.40	0.41	0.42	0.40
Na ₂ O	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
K ₂ O	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Total	99.29	100.60	100.20	99.75	99.80	98.37	99.60	99.60	99.60	99.60	99.60	99.60	99.60	99.60	99.60	99.62	100.50	100.40	100.20	99.54
Fee	50.54	51.50	41.15	40.50	51.98	45.42	54.38	54.38	54.38	54.38	54.38	54.38	54.38	54.38	54.38	43.77	39.45	40.53	39.74	40.56

Sample	OLIVINE ANALYSES					OLIVINE ANALYSES					OLIVINE ANALYSES					OLIVINE ANALYSES				
	8208.05	8208.05	8208.05	8208.05	8208.05	8208.08	8208.08	8208.08	8208.08	8208.08	8208.08	8208.08	8208.08	8208.08	8208.08	8209.02	8209.02	8209.02	8209.02	8209.02
Traverse	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	16	16	16	16	16
Along.Fen.	614	614	614	614	614	614	614	614	614	614	614	614	614	614	614	702	702	702	702	702
Across.Fen.	-15.35	-15.35	-15.35	-15.35	-15.35	-60	-60	-60	-60	-60	-60	-60	-60	-60	-60	1	1	1	1	1
Thickness	148	148	148	148	148	148	148	148	148	148	148	148	148	148	148	85	85	85	85	85
Circles	2.00	2.00	2.00	2.00	2.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	2.00
Grains	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Rim-Core	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	RIM	INTER.	INTER.	INTER.	INTER.	INTER.
Adjacent	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
SiO ₂	33.39	35.54	34.91	34.86	35.41	35.19	35.33	35.33	35.33	35.33	35.33	35.33	35.33	35.33	35.33	35.44	34.73	35.35	35.35	35.30
TiO ₂	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Al ₂ O ₃	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Cr ₂ O ₃	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
FeO	50.36	36.53	40.74	39.23	37.48	38.74	38.55	38.55	38.55	38.55	38.55	38.55	38.55	38.55	38.55	38.52	43.45	40.34	39.55	39.55
MnO	1.15	0.57	0.73	0.67	0.64	0.69	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.63	0.84	0.70	0.65	0.65
NiO	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
MgO	15.86	26.57	23.01	24.69	25.83	25.10	25.24	25.24	25.24	25.24	25.24	25.24	25.24	25.24	25.24	25.43	21.36	23.96	24.40	24.40
NaO	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
CaO	0.30	0.25	0.21	0.24	0.26	0.24	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.25	0.32	0.28	0.31	0.31
Na ₂ O	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
K ₂ O	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Total	101.10	99.46	99.60	99.71	99.77	99.96	100.10	100.10	100.10	100.10	100.10	100.10	100.10	100.10	100.10	100.30	100.70	100.60	100.60	100.20
Fee	35.95	56.45	50.16	50.86	55.12	53.59	53.85	53.85	53.85	53.85	53.85	53.85	53.85	53.85	53.85	54.05	46.70	51.42	51.42	52.37

Table A3.1

Sample	ILMENITE ANALYSES					ILMENITE ANALYSES					ILMENITE ANALYSES					ILMENITE ANALYSES				
	8428.03	8428.03	8428.03	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07	8428.07
Transverse	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Along Pos.	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173	173
Across Pos.	-25.3	-25.3	-25.3	-25.3	-25.3	-25.3	-25.3	-25.3	-25.3	-25.3	-25.3	-25.3	-25.3	-25.3	-25.3	-25.3	-25.3	-25.3	-25.3	-25.3
Thickness	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5	88.5
Circles	100.00	100.00	100.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00
Grains	1.00	2.00	2.00	1.00	2.00	2.00	1.00	2.00	2.00	1.00	2.00	2.00	1.00	2.00	2.00	1.00	2.00	2.00	1.00	2.00
Min-Corr	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Adjacent	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
SiO ₂	49.30	49.56	49.93	49.76	49.45	49.10	49.34	49.16	49.18	49.73	49.57	49.20	49.36	49.37	49.36	49.37	49.36	49.37	49.36	49.37
Al ₂ O ₃	0.05	0.10	0.07	0.07	0.02	0.03	0.04	0.05	0.11	0.36	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr ₂ O ₃	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
FeO	46.62	46.75	46.50	46.31	47.12	46.95	47.12	47.29	46.57	45.87	46.04	47.07	47.39	47.63	47.39	47.63	47.39	47.63	47.39	47.63
MnO	0.72	0.73	0.74	0.77	0.74	0.75	0.72	0.74	0.69	0.72	0.70	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
NiO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
MgO	1.18	0.92	1.05	1.13	0.61	0.57	0.65	0.34	1.76	1.66	1.68	0.33	0.39	0.33	0.39	0.33	0.39	0.33	0.39	0.33
BaO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CaO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Na ₂ O	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
K ₂ O	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Total	97.87	98.07	98.27	98.04	97.93	97.41	97.87	97.58	98.32	98.35	98.15	97.35	97.89	98.08	97.35	97.89	97.35	98.08	97.89	98.08
Time	94.51	95.06	95.51	95.31	95.18	95.06	95.00	95.18	93.39	94.61	94.32	95.49	95.22	95.09	95.49	95.22	95.09	95.49	95.22	95.09

Sample	ILMENITE ANALYSES					ILMENITE ANALYSES					ILMENITE ANALYSES					ILMENITE ANALYSES				
	8401.24	8401.24	8401.24	8401.15	8401.15	8401.15	8401.18	8401.18	8401.18	8401.18	8401.18	8401.18	8401.18	8401.18	8401.18	8401.18	8401.18	8401.18	8401.18	8401.18
Transverse	7	7	7	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
Along Pos.	243	243	243	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427	427
Across Pos.	78.5	78.5	78.5	-52.5	-52.5	-52.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5	15.5
Thickness	209.5	209.5	209.5	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220
Circles	100.00	100.00	100.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00	200.00
Grains	1.00	2.00	2.00	1.00	2.00	2.00	1.00	2.00	2.00	1.00	2.00	2.00	1.00	2.00	2.00	1.00	2.00	2.00	1.00	2.00
Min-Corr	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Adjacent	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
SiO ₂	48.81	49.60	49.53	50.36	50.05	49.92	50.12	49.86	49.65	49.67	49.45	49.22	49.37	49.64	49.22	49.37	49.64	49.22	49.37	49.64
Al ₂ O ₃	0.06	0.03	0.06	0.08	0.08	0.05	0.01	0.06	0.06	0.04	0.06	0.07	0.05	0.06	0.07	0.05	0.06	0.07	0.05	0.06
Cr ₂ O ₃	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
FeO	47.45	47.80	46.77	46.60	46.56	46.61	47.06	47.10	47.88	48.03	47.53	47.58	47.63	47.35	47.58	47.63	47.35	47.58	47.63	47.35
MnO	0.79	0.82	0.75	0.94	0.91	0.78	0.78	0.79	0.83	0.83	0.86	0.93	0.89	0.92	0.93	0.89	0.92	0.93	0.89	0.92
NiO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
MgO	0.70	0.78	0.96	0.35	0.55	0.64	0.46	0.52	0.33	0.15	0.34	0.15	0.10	0.08	0.15	0.10	0.08	0.15	0.10	0.08
BaO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
CaO	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Na ₂ O	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
K ₂ O	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Total	97.81	98.03	98.06	98.33	98.15	98.00	98.43	98.33	98.75	98.72	98.24	97.95	98.03	98.04	97.95	98.03	98.04	97.95	98.03	98.04
Time	93.96	95.26	94.94	96.85	96.25	96.06	96.15	95.70	95.00	95.20	95.10	95.08	95.33	95.89	95.08	95.33	95.89	95.08	95.33	95.89

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Table A3.1

Sample	ELEMENT ANALYSES									
	8418.03	8418.03	8418.03	8418.03	8209.04	8209.04	8209.04	8209.04	8209.04	8209.04
Transverse	14	14	14	14	16	16	16	16	16	16
Along Pos.	427	427	427	427	702	702	702	702	702	702
Across Pos.	-78.65	-78.65	-78.65	-78.65	17.35	17.35	17.35	17.35	17.35	17.35
Thickness	220	220	220	220	85	85	85	85	85	85
Circle	200.00	200.00	200.00	200.00	100.00	100.00	100.00	100.00	100.00	100.00
Grain	1.00	2.00	3.00	3.00	1.00	2.00	3.00	3.00	4.00	4.00
Rim-Core	C	C OR I	C	C	C	C	C	C	C	C
Adjacent	--	--	--	--	--	--	--	--	--	--
SiO ₂	--	--	--	--	--	--	--	--	--	--
TiO ₂	50.08	50.33	50.20	50.20	50.38	50.29	50.41	50.41	50.47	50.47
Al ₂ O ₃	0.02	0.03	0.02	0.02	0.07	0.10	0.08	0.08	0.10	0.10
Cr ₂ O ₃	--	--	--	--	--	--	--	--	--	--
FeO	45.75	45.75	46.14	46.14	45.74	45.74	45.43	45.43	45.23	45.23
MnO	0.75	0.79	0.76	0.76	0.70	0.78	0.71	0.71	0.74	0.74
NiO	--	--	--	--	--	--	--	--	--	--
MgO	1.06	1.16	1.09	1.09	1.60	1.57	1.57	1.57	1.62	1.62
NaO	--	--	--	--	--	--	--	--	--	--
CaO	--	--	--	--	--	--	--	--	--	--
Na ₂ O	--	--	--	--	--	--	--	--	--	--
K ₂ O	--	--	--	--	--	--	--	--	--	--
Total	97.67	98.06	98.20	98.20	98.49	98.48	98.20	98.20	98.16	98.16
Loss	96.34	96.60	96.04	96.04	95.73	95.59	96.11	96.11	96.23	96.23

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Table A3.1

Sample	GPH-HOPKINS AENE ANALY. E.				GPH-HOPKINS AENE ANALY. E.				GPH-HOPKINS AENE ANALY. E.			
	8404.14	8404.14	8404.14	8404.14	8201.04	8201.04	8201.03	8201.03	8201.03	8201.03	8201.03	8201.03
Transverse	10	10	10	10	11	11	11	11	11	11	11	11
Along Pot	330	330	330	330	337	337	337	337	337	337	337	337
Across Pot	-93.075	-93.075	-93.075	-93.075	-15.65	-15.65	32.75	32.75	32.75	32.75	32.75	32.75
Thickness	186.55	186.55	186.55	186.55	160.5	160.5	160.5	160.5	160.5	160.5	160.5	160.5
Circles	1.00	1.00	1.00	1.00	4.00	4.00	2.00	2.00	3.00	6.00	7.00	7.00
Grates	1.00	1.00	2.00	2.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Rim-Core	--	--	--	--	RIM	CORE	--	--	CORE	--	--	--
Adjacent	--	--	--	--	--	--	--	--	--	--	--	--
SiO ₂	52.64	52.69	52.94	53.27	49.42	49.65	49.74	49.25	49.21	49.68	49.97	49.68
TiO ₂	0.32	0.28	0.28	0.21	0.11	0.06	0.09	0.11	0.09	0.09	0.09	0.11
Al ₂ O ₃	1.01	0.91	0.80	0.68	0.11	0.08	0.13	0.17	0.06	0.13	0.13	0.13
Cr ₂ O ₃	--	--	--	--	0.03	0.05	0.02	0.03	0.04	0.05	0.03	0.01
Fe ₂ O ₃	22.74	23.40	22.30	23.04	39.75	39.41	36.71	38.86	39.67	37.50	36.33	37.34
MnO	0.63	0.66	0.62	0.63	0.91	0.93	1.02	1.03	0.96	0.98	0.97	0.94
NiO	--	--	--	--	--	--	--	--	--	--	--	--
MgO	21.85	21.35	22.05	21.82	9.00	9.30	11.11	9.54	9.24	10.67	10.98	10.87
BaO	--	--	--	--	--	--	--	--	--	--	--	--
CaO	1.26	1.50	1.32	1.22	1.11	0.96	1.24	1.62	1.17	1.26	1.29	1.30
Na ₂ O	0.00	0.00	0.00	0.00	0.04	0.01	0.00	0.00	0.01	0.00	0.00	0.04
K ₂ O	--	--	--	--	--	--	--	--	--	--	--	--
Total	100.50	101.00	100.30	100.90	100.50	100.50	100.10	100.60	100.50	100.40	99.79	100.40
Exp	63.13	61.92	63.79	62.79	28.75	29.60	35.04	30.43	29.33	33.64	35.00	34.16

(Continued on next page)

Table A3.1

PREHNITE (RADIATING MINERAL)			
Sample	8208.02	8208.02	8208.02
Traverse	15	15	15
Along Pos.	614	614	614
Across Pos.	1	1	1
Thickness	148	148	148
Circles	1	2	2
Grains	1	1	1
Rim-Core	--	--	--
Adjacent	--	--	--
SiO ₂	43.64	43.56	43.77
TiO ₂	0.00	0.00	0.00
Al ₂ O ₃	23.73	24.07	23.83
Cr ₂ O ₃	--	--	--
FeO†	0.62	0.27	0.25
MnO	0.08	0.01	0.02
NiO	--	--	--
MgO	0.00	0.00	0.00
BaO	--	--	--
CaO	25.96	25.58	25.86
Na ₂ O	0.12	0.13	0.12
K ₂ O	0.00	0.00	0.00
Total	94.14	93.74	93.66

CHAMOSITE (SEE DELESSITE IN FRONDEL, 1955)			
Sample	8401.13	8401.13	8401.13
Traverse	7	7	7
Along Pos.	243	243	243
Across Pos.	-28.6	-28.6	-28.6
Thickness	209.5	209.5	209.5
Circles	2	1	1
Grains	1	1	1
Rim-Core	--	--	--
Adjacent	--	--	--
SiO ₂	28.73	28.73	28.73
TiO ₂	0.07	0.07	0.07
Al ₂ O ₃	11.06	11.06	11.06
Cr ₂ O ₃	--	--	--
FeO†	42.00	42.00	42.00
MnO	0.43	0.43	0.43
NiO	--	--	--
MgO	7.04	7.04	7.04
BaO	--	--	--
CaO	0.15	0.15	0.15
Na ₂ O	0.03	0.03	0.03
K ₂ O	0.00	0.00	0.00
Total	89.49	89.49	89.49

BIOTITE			
Sample	8401.13	8401.13	8401.13
Traverse	7	7	7
Along Pos.	243	243	243
Across Pos.	-28.6	-28.6	-28.6
Thickness	209.5	209.5	209.5
Circles	1	1	1
Grains	1	1	1
Rim-Core	--	--	--
Adjacent	--	--	--
SiO ₂	35.46	35.43	35.46
TiO ₂	5.57	6.05	5.98
Al ₂ O ₃	11.53	12.20	11.83
Cr ₂ O ₃	--	--	--
FeO†	30.00	28.25	29.50
MnO	0.20	0.24	0.19
NiO	--	--	--
MgO	5.39	7.71	5.94
BaO	--	--	--
CaO	0.18	0.08	0.04
Na ₂ O	0.67	0.69	0.69
K ₂ O	8.30	7.21	8.21
Total	97.30	96.16	97.92

UK. RED BIOTITE			
Sample	8401.13	8401.13	8401.13
Traverse	7	7	7
Along Pos.	243	243	243
Across Pos.	-28.6	-28.6	-28.6
Thickness	209.5	209.5	209.5
Circles	1	1	1
Grains	1	2	2
Rim-Core	--	--	--
Adjacent	--	--	--
SiO ₂	35.46	35.77	35.54
TiO ₂	5.57	6.05	5.98
Al ₂ O ₃	11.53	11.80	11.83
Cr ₂ O ₃	--	--	--
FeO†	30.00	28.86	29.50
MnO	0.20	0.26	0.19
NiO	--	--	--
MgO	5.39	5.60	5.94
BaO	--	--	--
CaO	0.18	0.08	0.04
Na ₂ O	0.67	0.67	0.69
K ₂ O	8.30	8.48	8.21
Total	97.30	97.57	97.92

PECTOLITE (CLEAR WITH HIGH BIREFRINGENCE)			
Sample	8401.13	8401.13	8401.13
Traverse	7	7	7
Along Pos.	243	243	243
Across Pos.	-28.6	-28.6	-28.6
Thickness	209.5	209.5	209.5
Circles	1	1	1
Grains	1	1	1
Rim-Core	--	--	--
Adjacent	--	--	--
SiO ₂	54.18	53.71	53.71
TiO ₂	0.01	0.01	0.05
Al ₂ O ₃	0.07	0.07	0.26
Cr ₂ O ₃	--	--	--
FeO†	0.54	0.54	0.75
MnO	0.87	0.87	0.27
NiO	--	--	--
MgO	0.00	0.00	0.01
BaO	--	--	--
CaO	32.31	33.08	33.08
Na ₂ O	8.94	8.81	8.81
K ₂ O	0.00	0.00	0.00
Total	96.93	96.93	96.94

APPENDIX 4: MINERAL ZONING

A4.1 EXPLANATION OF TABLE A4.1

Core and rim compositions of individual mineral grains are compared. Headings are the same as in Appendix 3 except that **Core Minus Rim** indicates subtraction of **Rim** composition from **Core** composition.

Table A4.1: Mineral zoning

OLIVINE									
Sample #	Traverse #	Across Dyke Position	Circle #	Grain #	Rim (Fo#)	Intern. (Fo#)	Core (Fo#)	Core Minus Rim	Adjacent Mineral
RE8428.07	2	17.15	1	1	32.13	-	39.38	7.25	Fe-Ti Ox.
RE8428.07	2	17.15	1	1	42.04	-	39.38	-2.66	Feldspar
RE8428.07	2	17.15	1	1	35.94	-	39.38	3.44	Feldspar
RE8428.07	2	17.15	1	1	31.65	-	39.38	7.73	Fe-Ti Ox.
RE8428.07	2	17.15	2	1	51.20	-	51.99	0.79	Cpx
RE8428.07	2	17.15	3	1	50.26	-	52.50	2.24	Feldspar
RE8428.07	2	17.15	3	1	34.19	48.62	52.50	18.31	Fe-Ti Ox.
RE8428.07	2	17.15	3	1	50.83	-	52.50	1.67	Cpx
RE8428.07	2	17.15	3	1	50.83	-	56.36	-0.67	Cpx
RE8428.03	2	-25.30	1	1	57.03	-	56.74	-0.29	Cpx
RE8428.03	2	-25.30	2	1	48.56	49.70	52.70	4.14	Cpx
RE8428.03	2	-25.30	3	1	-	46.81	45.80	-	Feldspar
RE8203.11	5	-10.60	3	1	29.92	-	29.68	-0.24	-
RE8203.13	5	-34.35	3	1	57.38	-	59.29	1.91	-
RE8203.13	5	-34.35	2	1	57.68	-	57.22	-0.46	-
RE8401.55	7	89.75	1	1	63.04	-	63.37	0.33	-
RE8401.55	7	89.75	2	1	56.35	-	57.27	-0.08	-
RE8401.55	7	89.75	4	1	61.32	-	61.13	-0.19	-
RE8401.06	7	-88.75	1	1	44.51	-	44.45	-0.06	-
RE8401.06	7	-88.75	3	1	55.79	55.89	56.16	0.37	Cpx
RE8401.06	7	-88.75	4	1	43.44	-	45.15	1.71	-
RE8401.13	7	-28.60	1	1	15.56	-	19.46	3.90	-
RE8401.13	7	-28.60	3	1	17.78	-	22.40	4.62	Fe-Ti Ox.
RE8401.13	7	-28.60	4	1	13.06	-	22.13	9.07	Biotite
RE8401.13	7	-28.60	5	1	22.48	-	27.19	4.71	Cpx
RE8401.13	7	-28.60	5	1	18.55	-	27.19	8.64	Feldspar
RE8401.54	7	88.25	1	1	58.70	-	58.17	-0.53	Feldspar
RE8401.54	7	88.25	1	1	58.74	-	58.17	-0.57	-
RE8401.54	7	88.25	1	1	58.51	-	58.17	-0.34	Cpx
RE8401.54	7	88.25	2	1	54.31	-	54.02	-0.29	Cpx
RE8401.54	7	88.25	2	1	54.57	-	54.02	-0.55	Cpx
RE8401.54	7	88.25	4	1	54.15	-	53.85	-0.30	Feldspar
RE8401.22	7	63.50	2	1	32.20	-	32.05	-0.15	Cpx
RE8401.22	7	63.50	3	1	34.85	-	35.89	1.04	Feldspar
RE8401.22	7	63.50	4	1	30.27	-	32.33	2.06	Feldspar
RE8401.23	7	69.85	1	1	37.10	-	39.04	1.94	Biotite
RE8401.23	7	69.85	4	1	40.19	-	41.42	1.23	Feldspar
RE8401.23	7	69.85	5	1	38.15	-	41.46	3.31	Apatite
RE8401.57	7	61.64	1	1	35.82	-	36.89	1.07	Feldspar
RE8401.57	7	61.64	3	1	34.01	-	34.93	0.92	Cpx
RE8401.57	7	61.64	4	1	30.88	-	30.03	-0.85	Feldspar
RE8401.20	7	36.75	1	1	25.22	-	24.71	-0.51	-
RE8401.20	7	36.75	2	1	20.52	-	25.36	4.84	-
RE8401.20	7	36.75	5	1	20.02	-	25.29	5.27	Feldspar
RE8401.24	7	78.50	1	1	48.47	-	49.16	0.69	Feldspar
RE8401.24	7	78.50	2	1	46.91	-	50.32	3.41	Feldspar
RE8401.24	7	78.50	4	1	49.85	-	49.89	0.04	Feldspar

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Table A4.1

OLIVINE (continued)

Sample #	Traverse #	Across Dyke Position	Circle #	Grain #	Rim (Fo#)	Intern. (Fo#)	Core (Fo#)	Core Minus Rim	Adjacent Mineral
RE8401.58	7	66.05	1	1	35.04	-	42.96	7.92	Fe-Ti Ox.
RE8401.58	7	66.05	1	1	40.32	-	42.96	2.64	Feldspar
RE8401.58	7	66.05	3	1	44.56	-	44.62	0.06	Cpx
RE8401.58	7	66.05	4	1	43.99	-	44.94	0.95	Feldspar
RE8401.08	7	-71.00	2	1	21.03	-	20.35	-0.68	Cpx
RE8401.08	7	-71.00	3	1	20.47	-	25.21	4.74	Feldspar
RE8401.08	7	-71.00	6	1	-	16.15	14.42	-	Feldspar
RE8401.08	7	-71.00	6	1	9.71	-	14.42	4.71	-
RE8401.07	7	-77.10	2	1	49.64	-	49.76	0.12	Feldspar
RE8401.07	7	-77.10	2	1	42.44	-	49.76	7.32	Fe-Ti Ox
RE8401.07	7	-77.10	2	1	48.17	-	49.76	1.59	Cpx
RE8401.07	7	-77.10	3	1	-	47.82	48.78	-	-
RE8401.07	7	-77.10	3	1	-	49.52	48.78	-	-
RE8404.14	10	-93.08	3	1	56.63	56.90	-	-	Feldspar
RE8201.03	11	32.75	1	1	21.76	21.65	22.42	0.66	-
RE8201.03	11	32.75	4	1	-	20.83	21.32	-	-
RE8201.04	11	-15.65	3	1	19.78	-	26.06	6.28	-
RE8201.04	11	-15.65	3	2	22.95	-	22.40	-0.55	-
RE8207.15	14	-35.50	1	1	53.88	-	54.27	0.39	-
RE8207.15	14	-35.50	2	1	49.95	-	51.03	1.58	-
RE8207.15	14	-35.50	4	1	56.32	-	57.97	1.65	-
RE8207.15	14	-35.50	5	1	52.87	-	54.41	1.54	-
RE8418.16	14	-21.50	1	1	33.44	-	34.44	1.00	Feldspar
							36.04	2.60	Feldspar
RE8418.15	14	-52.50	4	1	29.68	-	36.01	6.33	Feldspar
RE8418.15	14	-52.50	4	1	29.28	-	36.01	6.73	-
RE8418.15	14	-52.50	2	1	33.43	-	34.99	1.56	Cpx
RE8418.15	14	-52.50	2	1	32.95	-	34.99	2.04	Feldspar
RE8418.15	14	-52.50	1	1	32.36	-	33.13	0.77	Feldspar
RE8418.15	14	-52.50	1	1	29.84	-	33.13	3.29	Feldspar
RE8418.18	14	15.50	3	1	28.17	-	29.21	1.04	Feldspar
							25.34	-2.83	Feldspar
RE8418.18	14	15.50	3	1	19.05	-	29.21	10.16	Feldspar
							25.34	6.29	Feldspar
RE8418.18	14	15.50	4	1	26.61	-	23.86	-2.75	Feldspar
RE8418.18	14	15.50	4	1	-	21.32	23.86	-	Fe-Ti Ox.
RE8418.18	14	15.50	5	1	33.71	-	32.42	-1.29	Cpx
							33.06	-0.65	Cpx
RE8418.18	14	15.50	5	1	30.64	-	32.42	1.78	Feldspar
							33.06	2.42	Feldspar
RE8418.03	14	-78.65	1	1	51.75	-	53.77	2.02	Feldspar
RE8418.03	14	-78.65	3	1	33.59	-	37.06	3.47	Fe-Ti Ox.
RE8418.03	14	-78.65	3	1	37.77	-	37.06	-0.71	Feldspar
RE8418.03	14	-78.65	4	1	45.92	-	45.81	-0.11	Feldspar
RE8208.06	15	-30.65	3	1	51.08	-	52.48	1.40	-
RE8208.06	15	-30.65	3	2	50.54	-	51.50	0.96	-

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Table A4.1

OLIVINE (continued)

Sample #	Traverse #	Across Dyke Position	Circle #	Grain #	Rim (Fo#)	Intern. (Fo#)	Core (Fo#)	Core Minus Rim	Adjacent Mineral
RE8208.04	15	13.00	1	1	40.50	-	41.15	0.65	Feldspar
RE8208.04	15	13.00	2	1	45.42	-	51.98	6.56	Feldspar
RE8208.04	15	13.00	3	1	55.65	-	54.38	-1.27	Feldspar
RE8208.04	15	13.00	3	1	40.71	-	54.38	13.67	Fe-Ti Ox.
RE8208.05	15	-15.35	1	1	40.53	-	43.77	3.24	-
							39.45	-1.08	-
RE8208.05	15	-15.35	2	1	35.95	-	39.74	3.79	Feldspar
							40.56	4.61	Feldspar
RE8208.08	15	-60.00	1	1	50.16	-	56.45	6.29	Feldspar
RE8208.08	15	-60.00	3	1	53.98	-	62.01	8.03	Fe-Ti Ox.
RE8208.08	15	-60.00	3	1	54.89	-	62.01	7.12	Feldspar
RE8209.02	16	1.00	1	1	-	46.70	51.42	-	Fe-Ti Ox.
							54.05	-	Fe-Ti Ox.
RE8209.02	16	1.00	2	1	50.97	-	52.37	1.40	Feldspar
RE8209.02	16	1.00	2	1	46.23	-	52.37	6.14	Fe-Ti Ox.
RE8209.02	16	1.00	2	2	52.66	-	53.01	0.35	Olivine
RE8209.02	16	1.00	3	1	45.04	-	49.98	4.94	-
RE8209.02	16	1.00	3	1	46.89	-	49.98	3.09	Feldspar
RE8209.04	16	17.35	2	1	58.45	-	56.24	-2.21	Cpx
RE8209.04	16	17.35	2	1	53.66	-	56.24	2.58	Olivine
RE8209.04	16	17.35	3	1	40.40	46.16	50.11	9.71	Fe-Ti Ox.
RE8209.06	16	32.10	1	1	44.98	-	49.26	4.28	Feldspar
RE8209.06	16	32.10	2	1	55.01	-	55.51	0.50	Feldspar
RE8209.06	16	32.10	3	1	56.50	-	56.32	-0.18	Feldspar

CLINOPYROXENE

Sample #	Traverse #	Across Dyke Position	Circle #	Grain #	Rim (En#)	Intern. (En#)	Core (En#)	Core Minus Rim	Adjacent Mineral
RE8428.07	2	17.15	2	1	63.22	-	63.02	-0.20	Olivine
RE8428.07	2	17.15	2	1	62.19	-	63.02	0.83	Feldspar
RE8428.07	2	17.15	3	1	68.12	-	68.37	0.25	Olivine
RE8428.07	2	17.15	3	1	66.67	-	68.37	1.70	Fe-Ti Ox.
RE8203.13	5	-34.35	2	1	67.26	-	67.37	0.11	-
RE8203.13	5	-34.35	2	2	68.55	-	67.46	-1.09	-
RE8203.11	5	-10.60	2	1	53.52	-	57.27	3.75	-
RE8401.55	7	-89.75	2	1	69.38	-	70.22	0.84	-
RE8401.55	7	-89.75	3	1	72.55	-	72.56	0.01	-
RE8401.55	7	-89.75	5	1	69.30	-	68.52	-0.78	-
RE8401.66	7	-88.75	1	1	63.64	-	64.69	1.05	Olivine
RE8401.66	7	-88.75	2	1	68.99	-	69.36	0.37	-
RE8401.66	7	-88.75	3	1	69.35	-	69.70	0.35	Olivine
RE8401.13	7	-28.60	2	1	60.73	60.51	56.58	-4.15	Feldspar
RE8401.13	7	-28.60	3	1	52.18	-	57.14	4.96	Olivine
RE8401.13	7	-28.60	3	1	52.31	-	57.14	4.83	Olivine
RE8401.13	7	-28.60	3	1	58.90	-	57.14	-1.76	Feldspar
RE8401.13	7	-28.60	5	1	58.70	-	59.98	1.28	Olivine
RE8401.13	7	-28.60	5	1	52.90	-	59.98	7.08	Feldspar

(Continued on next page)

Table A4.1

CLINOPYROXENE (continued)

Sample #	Traverse Across Dyke #	Position	Circle #	Grain #	Rim (En#)	Interm. (En#)	Core (En#)	Core Minus Rim	Adjacent Mineral
RE8401.54	7	88.25	1	1	70.37	-	70.03	-0.34	Feldspar
							69.81	-0.56	Feldspar
RE8401.54	7	88.25	1	1	69.66	-	70.03	0.37	Olivine
							69.81	0.15	Olivine
RE8401.54	7	88.25	2	1	70.61	-	69.63	-0.98	Feldspar
RE8401.54	7	88.25	2	1	69.86	-	69.63	-0.23	Olivine
RE8401.54	7	88.25	3	1	70.60	-	71.59	0.99	Feldspar
RE8401.54	7	88.25	5	1	69.60	-	69.28	-0.32	Feldspar
RE8401.08	7	-71.00	1	1	46.77	60.39	61.58	14.81	Olivine
RE8401.08	7	-71.00	2	1	59.84	-	60.77	0.93	Olivine
RE8401.08	7	-71.00	2	1	58.06	-	60.77	2.71	Feldspar
RE8401.08	7	-71.00	4	1	49.94	-	60.24	10.30	Olivine
RE8401.08	7	-71.00	4	1	59.41	-	60.24	0.83	Feldspar
RE8401.08	7	-71.00	4	1	50.47	-	60.24	9.77	Feldspar
RE8401.08	7	-71.00	4	1	49.26	-	60.24	10.98	Olivine
RE8201.04	11	-15.65	2	1	60.61	-	60.58	-0.03	-
RE8201.03	11	32.75	9	1	-	55.73	61.59	-	Fe-Ti Ox.
RE8201.03	11	32.75	9	1	50.99	-	61.59	10.60	-
RE8207.07	14	-3.50	2	1	55.29	56.61	67.39	12.10	-
RE8207.07	14	-3.50	2	2	60.68	-	58.29	-2.39	-
RE8207.15	14	-35.50	1	1	66.70	66.61	67.00	0.30	-
RE8207.15	14	-35.50	3	1	60.16	-	61.73	1.77	-
RE8207.15	14	-35.50	5	1	68.82	69.61	69.61	0.79	-
RE8418.03	14	-78.65	1	1	68.21	-	67.62	-0.59	Olivine
RE8418.03	14	-78.65	1	1	67.42	-	67.62	0.20	Feldspar
RE8418.03	14	-78.65	2	1	66.91	-	66.30	-0.61	Feldspar
RE8418.03	14	-78.65	3	1	60.69	-	60.78	0.09	Olivine
RE8418.03	14	-78.65	3	1	61.09	-	60.78	-0.31	Feldspar
RE8418.03	14	-78.65	5	1	61.53	-	62.61	1.08	Feldspar
RE8418.11	14	25.00	1	1	51.54	48.08	51.91	0.37	Feldspar
RE8418.11	14	25.00	2	1	51.86	52.67	57.30	5.44	Feldspar
RE8418.11	14	25.00	3	1	37.49	-	37.24	-0.25	Feldspar
RE8418.18	14	15.50	1	1	54.14	-	54.32	0.18	Feldspar
							55.14	1.00	Feldspar
RE8418.18	14	15.50	2	1	57.59	-	60.81	3.22	Feldspar
RE8418.18	14	15.50	5	1	65.03	-	64.77	-0.26	Olivine
RE8418.18	14	15.50	5	1	-	64.34	64.77	-	Fe-Ti Ox.
RE8418.18	14	15.50	5	1	60.15	-	64.77	4.62	Feldspar
RE8209.02	16	1.00	400	1	65.18	-	68.64	3.46	Fe-Ti Ox.
							69.50	4.32	Fe-Ti Ox.
RE8209.02	16	1.00	400	1	69.04	-	68.64	-0.40	Fe-Ti Ox.
							69.50	0.46	Fe-Ti Ox.
RE8209.02	16	1.00	400	1	68.98	-	68.64	-0.34	Feldspar
							69.50	0.52	Feldspar

(Continued on next page)

Table A4.1

FELDSPAR

Sample #	Traverse #	Across Dyke Position	Circle #	Grain #	Rim (An#)	Interm. (An#)	Core (An#)	Core Minus Rim	Adjacent Mineral
RE8203.13	5	-34.35	1	1	53.79	-	66.98	13.19	-
RE8203.13	5	-34.35	2	1	57.61	-	59.22	1.61	-
RE8203.11	5	10.60	3	1	27.73	-	16.21	-11.52	-
RE8201.04	1	-15.65	1	1	37.62	-	41.97	4.35	-
RE8207.07	4	-3.50	1	1	57.38	52.00	52.53	-4.85	-

APPENDIX 5: WHOLE-ROCK ANALYSES

A5.1 EXPLANATION OF TABLE A5.1

Along Position, Across Position, and Thickness are defined in Appendix 2. Description classifies samples into the following groups: HOSTROCK, SATellite DYKElet, DYKELET, BOULDER, CHILLED MARGIN, WEATHERed, CONTAMinated, VOLATILE?, HETERogenous, and DYKE. Those labelled HOSTROCK are samples from the hostrock (country rock). SATellite DYKElet are samples from thin satellite dykelets cutting the nearby adjacent host rock. DYKELET indicates a sample from a chilled dykelets cutting the main dyke. All remaining descriptive types apply to samples from the main dyke. The sample described by BOULDER? is from the main dyke but may not be in-situ. CHILLED MARGIN samples are from near the dyke margin. WEATHERed is from a visibly weathered dyke sample. CONTAMinated indicates chilled margin samples which were visibly altered. VOLATILE? are coarse- to medium-grained samples near the contact which may have crystallized in the presence of fluids. HETERogeneous is from a sample with two distinct grain sizes. DYKE indicates all remaining sample from the main dyke.

The major and minor element oxides abundances (SiO_2 , Al_2O_3 , TiO_2 , $\text{Fe}_2\text{O}_3\text{T}$, MgO , CaO , Na_2O , K_2O , P_2O_5 , and MnO), are in wt%. $\text{Fe}_2\text{O}_3\text{T}$ is total iron expressed as ferric iron. FeO (Calc) equals $0.71 \cdot \text{Fe}_2\text{O}_3\text{T}$, all in wt% (see Fig. 3.8). Remaining elements are in ppm. Eu^* is a hypothetical Eu abundance determined by interpolation from adjacent rare earth elements. Eu/Eu^* is termed the europium anomaly. The mineral abundances are from CIPW norms and are calculated from the whole rock chemistry. The tabulated analyses are not normalized volatile-free to 100%.

Ten analyses were not used for genetic modelling because of possible in-situ contamination and uncertain relationships with the dyke. Sample RE8204.08 has obvious weathering and much higher LOI contents (3.25%). Dyke-margin samples RE8207.09 and RE8418.13A are altered. Three samples from the dyke margin, RE8202.08, RE8202.05 and RE8202.02, show large variation in grain size (fine to coarse) and mineral proportions (the color index varies from 60 to 10). The coarser portions were probably fluid-rich during crystallization. Sample RE8401.47 is from a chilled margin which shows textural evidence of host rock contamination. Sample RE8404.15 is from the dyke contact and is a 'intimate' mixture of dyke and volcanic host rock material. A sample from the interior (RE8205.06) has Sc contents about twice as high as other samples (about 50 ppm) and has two distinct grain sizes. Sample RE8204.15 may be from a large boulder rather than an outcrop.

While all the chemical data is quoted to two decimal places, the analytical uncertainties are such that the data should not necessarily be considered accurate to two decimal places particularly for minor and trace elements (See Appendix 1).

Table A5.1

WHOLE-ROCK ANALYSES							
Sample#	8427.01	8427.02	8427.03	8428.14	8428.03	8428.06	8428.01
Traverse#	1.00	1.00	1.00	2.00	2.00	2.00	2.00
Along.Pos.	167.00	167.00	167.00	173.00	173.00	173.00	173.00
Across.Pos.	-40.25	-39.50	-29.75	-41.30	-25.30	-23.25	-14.10
Thickness	88.50	88.50	88.50	88.50	88.50	88.50	88.50
Descript.	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE
SiO ₂	45.56	46.20	48.06	45.52	46.24	46.50	47.52
TiO ₂	3.82	3.55	1.58	3.43	3.68	3.72	2.90
Al ₂ O ₃	18.63	18.29	21.85	17.14	16.65	17.58	18.05
Fe ₂ O ₃ T	13.86	17.44	9.14	14.16	14.51	13.23	12.95
FeO	10.30	9.44	6.62	10.61	10.70	9.83	9.55
FeO(calc)	9.84	9.54	6.49	10.05	10.30	9.39	9.19
MgO	6.59	5.04	5.42	5.36	4.92	4.23	4.04
CaO	8.79	9.37	9.95	9.09	9.08	9.23	9.03
Na ₂ O	3.12	3.34	3.48	3.42	3.43	3.46	3.51
K ₂ O	0.66	0.97	0.65	1.01	1.03	1.04	1.03
P ₂ O ₅	0.52	0.80	0.27	0.81	0.76	0.68	0.79
MnO	0.16	0.17	0.11	0.17	0.18	0.17	0.16
S	0.02	0.02	0.00	0.02	0.01	0.03	0.04
LOI	--	--	--	--	--	--	--
Total	100.57	100.14	99.77	98.95	99.30	98.78	98.96
Zr	83.00	116.00	71.00	110.00	115.00	111.00	113.00
Y	17.00	26.00	17.00	26.00	26.00	26.00	25.00
Nb	17.00	14.00	4.00	17.00	15.00	18.00	14.00
Zn	86.00	96.00	12.00	106.00	107.00	94.00	105.00
Ba	720.00	912.00	615.00	774.00	806.00	839.00	813.00
Rb	6.00	9.00	8.00	8.00	15.00	18.00	26.00
Sr	936.00	924.00	1167.00	878.00	807.00	857.00	871.00
V	368.00	239.00	120.00	--	--	--	--
Ni	43.00	24.00	41.00	32.00	14.00	14.00	16.00
Cr	76.65	62.69	129.80	--	--	--	--
Co	--	--	--	--	--	--	--
Ta	--	--	--	--	--	--	--
Sc	--	--	--	--	--	--	--
Hf	--	--	--	--	--	--	--
U	--	--	--	--	--	--	--
Th	--	--	--	--	--	--	--
La	--	--	--	--	--	--	--
Ce	--	--	--	--	--	--	--
Nd	--	--	--	--	--	--	--
Sm	--	--	--	--	--	--	--
Eu	--	--	--	--	--	--	--
Eu/Eu*	--	--	--	--	--	--	--
Tb	--	--	--	--	--	--	--
Yb	--	--	--	--	--	--	--
Lu	--	--	--	--	--	--	--
Qiz	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Or	3.88	5.72	3.85	6.03	6.13	6.22	6.15
Ab	26.25	28.23	28.29	27.11	29.23	29.64	30.02
An	34.69	32.01	42.18	28.74	27.19	29.74	30.79
Ne	0.00	0.00	0.66	1.16	0.00	0.00	0.00
Di	4.33	7.54	4.50	9.49	10.89	10.03	7.71
Opx	2.60	1.29	0.00	0.00	0.41	1.26	5.76
Ol	16.36	12.35	14.29	15.52	13.52	13.96	8.73
Mag	3.48	4.27	2.59	3.47	3.82	3.39	3.42
Ilm	7.21	6.73	3.01	6.58	7.04	7.15	5.57
Ap	1.22	1.89	0.64	1.94	1.81	1.63	1.89
Di (Ca)	2.21	3.84	2.31	4.80	5.51	5.07	3.88
Di (Mg)	1.27	2.12	1.36	2.45	2.75	2.51	1.82
Di (Fe)	0.84	1.58	0.83	2.23	2.64	2.46	2.01
Opx (Mg)	1.56	0.74	0.00	0.00	0.21	0.63	2.74
Opx (Fe)	1.04	0.55	0.00	0.00	0.20	0.62	3.02
Ol (Mg)	9.44	6.78	8.53	7.74	6.58	5.27	3.74
Ol (Fe)	6.93	5.57	5.76	7.78	6.94	5.69	4.79

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Table A5.1

WHOLE-ROCK ANALYSES

Sample#	8428.02	8428.05	8428.07	8428.08	8428.09	8428.11	8428.10
Traverse#	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Along.Pos.	173.00	173.00	173.00	173.00	173.00	173.00	173.00
Across.Pos.	-8.75	-0.95	17.15	25.75	36.40	43.55	43.75
Thickness	88.50	88.50	88.50	88.50	88.50	88.50	88.50
Descript.	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE
SiO ₂	49.41	48.23	46.88	47.49	46.64	46.81	46.83
TiO ₂	2.29	2.60	3.29	2.95	3.78	2.91	1.65
Al ₂ O ₃	18.61	17.69	17.46	19.24	17.65	19.45	19.95
Fe ₂ O ₃ T	11.06	12.01	13.49	11.92	13.47	12.20	11.40
FeO	7.36	8.42	10.10	8.80	8.70	8.80	8.50
FeO(calc)	7.85	8.53	9.58	8.46	9.56	8.66	8.09
NiO	2.19	3.60	4.18	4.81	3.52	5.06	7.84
CaO	9.02	9.46	8.93	9.21	9.18	9.55	9.29
Na ₂ O	4.09	3.70	3.54	3.53	3.62	3.37	3.08
K ₂ O	1.53	1.33	1.18	0.99	1.24	0.87	0.61
P ₂ O ₅	1.04	1.02	0.73	0.57	0.97	0.59	0.31
MnO	0.15	0.16	0.17	0.15	0.17	0.16	0.14
S	0.05	0.04	0.03	0.01	0.02	0.02	0.01
LOI	--	--	--	--	--	--	--
Total	98.62	98.90	98.76	99.89	99.29	100.01	100.16
Zr	154.00	127.00	128.00	99.00	128.00	101.00	73.00
Y	30.00	27.00	29.00	21.00	26.00	20.00	19.00
Nb	21.00	16.00	19.00	13.00	19.00	12.00	4.00
Zn	103.00	96.00	113.00	102.00	198.00	79.00	71.00
Ba	1099.00	970.00	897.00	738.00	1065.00	839.00	635.00
Rb	42.00	26.00	17.00	20.00	27.00	9.00	5.00
Sr	903.00	857.00	859.00	937.00	890.00	994.00	1022.00
V	--	--	--	--	--	208.00	92.00
Ni	0.00	11.00	18.00	23.00	8.00	32.00	100.00
Cr	--	--	--	--	--	71.59	46.41
Co	--	--	--	--	--	--	--
Ta	--	--	--	--	--	--	--
Sc	--	--	--	--	--	--	--
Hf	--	--	--	--	--	--	--
U	--	--	--	--	--	--	--
Th	--	--	--	--	--	--	--
La	--	--	--	--	--	--	--
Ce	--	--	--	--	--	--	--
Nd	--	--	--	--	--	--	--
Sm	--	--	--	--	--	--	--
Eu	--	--	--	--	--	--	--
Eu/Eu*	--	--	--	--	--	--	--
Tb	--	--	--	--	--	--	--
Yb	--	--	--	--	--	--	--
Lu	--	--	--	--	--	--	--
Qtz	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Or	9.17	7.95	7.06	5.86	7.38	5.14	3.60
Ab	35.11	31.66	30.33	29.90	30.85	28.49	25.25
An	28.30	28.05	28.63	33.77	28.46	35.38	38.75
Ne	0.00	0.00	0.00	0.00	0.00	0.01	0.42
Di	8.54	10.51	9.48	6.78	9.06	6.68	4.27
Opx	4.27	3.01	0.64	0.42	3.35	0.00	0.00
Ol	3.51	7.54	12.48	13.22	5.85	13.89	21.04
Mag	4.24	3.89	3.33	3.11	5.55	3.51	2.83
Ilm	4.41	4.99	6.33	5.61	7.23	5.53	3.13
Ap	2.50	2.44	1.75	1.35	2.31	1.40	0.73
Di (Ca)	4.26	5.30	4.77	3.45	4.61	3.40	2.19
Di (Mg)	1.78	2.56	2.23	1.84	2.49	1.86	1.31
Di (Fe)	2.50	2.65	2.48	1.50	1.96	1.42	0.77
Opx (Mg)	1.78	1.48	0.31	0.23	1.87	0.00	0.00
Opx (Fe)	2.49	1.53	0.34	0.19	1.48	0.00	0.00
Ol (Mg)	1.38	3.52	5.61	6.95	3.13	7.53	12.75
Ol (Fe)	2.13	4.02	6.87	6.27	2.72	6.36	8.29

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Table A5.1

WHOLE-ROCK ANALYSES							
Sample#	8428.15	8428.12A	8425.10	8425.13	8425.09	8425.08	8425.07
Traverse#	2.00	2.00	3.00	3.00	3.00	3.00	3.00
Along.Pos.	173.00	173.00	201.00	201.00	201.00	201.00	201.00
Across.Pos.	50.25	52.95	-72.00	-57.65	-57.00	-51.00	-27.50
Thickness	88.50	88.50	148.50	148.50	148.50	148.50	148.50
Descript.	SAT. DYKE	SAT. DYKE	DYKE	DYKE	DYKE	DYKE	DYKE
SiO ₂	44.60	45.10	42.18	47.32	46.76	47.57	47.76
TiO ₂	3.61	3.40	3.90	3.15	3.36	3.02	3.79
Al ₂ O ₃	15.94	15.21	16.41	17.81	17.64	18.35	16.65
Fe ₂ O ₃ T	14.99	14.34	15.58	13.26	13.46	12.78	13.7
FeO	--	9.90	10.26	9.30	--	8.96	9.25
FeO(calc)	10.64	10.18	11.06	9.41	9.56	9.07	9.49
MgO	6.40	6.27	7.65	5.36	5.08	4.94	4.13
CaO	9.10	8.59	9.91	9.08	8.74	9.19	8.02
Na ₂ O	3.01	3.31	2.46	3.55	3.55	3.50	3.71
K ₂ O	0.70	1.02	0.45	0.99	1.01	1.05	1.44
P ₂ O ₅	0.85	0.80	0.83	0.70	0.82	0.70	0.93
MnO	0.21	0.20	0.19	0.17	0.17	0.16	0.17
S	0.07	0.02	0.06	0.01	0.01	0.01	0.02
LOI	--	--	--	--	--	--	--
Total	98.30	97.16	98.48	100.36	99.54	100.27	98.96
Zr	117.00	103.00	52.00	111.00	117.00	107.00	127.00
Y	28.00	20.00	19.00	27.00	25.00	28.00	29.00
Nb	14.00	21.00	6.00	15.00	14.00	13.00	12.00
Zn	112.00	143.00	90.00	93.00	92.00	93.00	99.00
Ba	693.00	687.00	536.00	863.00	933.00	871.00	1050.00
Rb	4.00	18.00	1.00	12.00	12.00	12.00	22.00
Sr	746.00	513.00	931.00	892.00	888.00	923.00	785.00
V	230.00	--	402.00	223.00	207.00	200.00	244.00
Ni	50.00	41.00	65.00	26.00	33.00	23.00	10.00
Cr	48.53	--	46.48	54.19	47.68	40.33	43.23
Co	--	--	--	--	--	--	--
Ta	--	--	--	--	--	--	--
Sc	--	--	--	--	--	--	--
Hf	--	--	--	--	--	--	--
U	--	--	--	--	--	--	--
Th	--	--	--	--	--	--	--
La	--	--	--	--	--	--	--
Ce	--	--	--	--	--	--	--
Nd	--	--	--	--	--	--	--
Sm	--	--	--	--	--	--	--
Eu	--	--	--	--	--	--	--
Eu/Eu ⁺	--	--	--	--	--	--	--
Tb	--	--	--	--	--	--	--
Yb	--	--	--	--	--	--	--
Lu	--	--	--	--	--	--	--
Qtz	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Or	4.21	6.21	2.70	5.83	5.99	6.19	8.60
Ab	25.93	28.83	21.15	29.93	30.17	29.53	31.72
An	28.42	24.33	32.93	29.63	29.36	31.18	24.79
Ne	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Di	9.73	11.56	9.32	8.76	7.25	7.98	7.64
Gpx	4.59	1.09	2.43	1.25	2.72	2.61	7.91
Ol	13.47	14.45	15.84	12.79	12.04	11.08	5.36
Mag	4.67	4.98	6.15	4.23	4.14	4.08	4.53
Ilm	6.98	6.65	7.53	5.96	6.41	5.72	7.27
Ap	2.05	1.95	2.00	1.65	1.95	1.65	2.22
Di (Ca)	4.97	5.92	4.81	4.47	3.69	4.06	3.88
Di (Mg)	2.78	3.42	3.03	2.48	1.99	2.22	2.06
Di (Fe)	1.98	2.23	1.48	1.82	1.57	1.70	1.70
Opx (Mg)	2.68	0.66	1.64	0.72	1.52	1.48	4.33
Opx (Fe)	1.91	0.43	0.80	0.53	1.20	1.13	3.58
Ol (Mg)	7.54	8.41	10.30	7.08	6.45	6.01	2.81
Ol (Fe)	5.92	6.04	5.54	5.71	5.60	5.08	2.55

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WHOLE-ROCK ANALYSES							
Sample#	8425.06	8425.12	8425.05	8425.04	8425.03	8425.02	8425.01A
Traverse#	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Along.Pos.	201.00	201.00	201.00	201.00	201.00	201.00	201.00
Across.Pos.	-16.50	3.25	25.50	29.75	39.25	54.50	56.65
Thickness	148.50	148.50	148.50	148.50	148.50	148.50	148.50
Descript.	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE
SiO ₂	46.97	47.42	46.77	47.33	47.65	46.24	49.62
TiO ₂	4.39	4.24	4.35	4.18	4.17	4.26	3.58
Al ₂ O ₃	16.68	16.07	16.30	16.37	15.63	16.43	17.30
Fe ₂ O ₃ T	14.42	14.26	14.53	14.20	14.10	13.73	10.69
FeO	10.18	10.17	9.97	10.04	9.42	9.83	--
FeO(calc)	10.24	10.12	10.32	10.08	10.01	9.75	7.59
MgO	4.34	4.32	4.48	4.23	4.29	4.49	3.48
CaO	7.59	8.04	8.35	8.26	8.62	9.02	8.83
Na ₂ O	3.35	3.66	3.59	3.53	3.57	3.26	3.91
K ₂ O	1.30	1.35	1.28	1.31	1.27	1.14	0.85
P ₂ O ₅	0.85	0.89	0.96	0.85	0.82	0.66	0.88
MnO	0.18	0.19	0.19	0.18	0.18	0.17	0.14
S	0.02	0.01	0.02	0.03	0.03	0.02	0.00
LOI	--	--	--	--	--	--	--
Total	99.46	99.32	99.71	99.35	99.28	98.33	98.44
Zr	138.00	142.00	140.00	141.00	142.00	116.00	112.00
Y	29.00	32.00	26.00	29.00	31.00	25.00	28.00
Nb	18.00	20.00	19.00	20.00	16.00	18.00	16.00
Zn	110.00	109.00	106.00	117.00	102.00	90.00	94.00
Ba	1038.00	1113.00	1020.00	1135.00	1040.00	891.00	775.00
Rb	18.00	19.00	21.00	17.00	16.00	16.00	20.00
Sr	791.00	744.00	754.00	757.00	705.00	772.00	790.00
V	230.00	227.00	223.00	381.00	282.00	430.00	260.00
Ni	7.00	14.00	17.00	19.00	3.00	11.00	4.00
Cr	34.53	52.81	63.19	45.44	36.68	0.00	63.73
Co	--	--	--	--	--	--	--
Ta	--	--	--	--	--	--	--
Sc	--	--	--	--	--	--	--
Hf	--	--	--	--	--	--	--
U	--	--	--	--	--	--	--
Th	--	--	--	--	--	--	--
La	--	--	--	--	--	--	--
Ce	--	--	--	--	--	--	--
Nd	--	--	--	--	--	--	--
Sm	--	--	--	--	--	--	--
Eu	--	--	--	--	--	--	--
Eu/Eu ⁺	--	--	--	--	--	--	--
Tb	--	--	--	--	--	--	--
Yb	--	--	--	--	--	--	--
Lu	--	--	--	--	--	--	--
Qtz	0.00	0.00	0.00	0.00	0.00	0.00	1.45
Or	7.72	8.03	7.58	7.79	7.56	6.85	5.10
Ab	32.75	31.18	30.47	30.07	30.43	28.06	33.61
An	24.53	23.60	24.66	25.12	23.05	27.29	27.58
Ne	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Di	6.38	8.84	8.70	8.70	11.99	11.37	9.09
Opx	4.67	7.56	6.15	8.83	9.28	5.78	10.87
Ol	9.04	6.29	6.90	5.07	2.50	6.72	0.00
Mag	4.53	4.32	5.02	4.44	5.31	4.14	3.32
Ilm	8.38	8.11	8.29	7.99	7.98	8.23	6.91
Ap	2.02	2.12	2.28	2.03	1.96	1.59	2.12
Di (Ca)	3.24	4.48	4.43	4.41	6.11	5.78	4.63
Di (Mg)	1.70	2.31	2.41	2.27	3.41	3.10	2.56
Di (Fe)	1.45	2.05	1.86	2.02	2.47	2.50	1.90
Opx (Mg)	2.52	4.00	3.47	4.67	5.38	3.20	6.25
Opx (Fe)	2.15	3.56	2.68	4.15	3.90	2.58	4.63
Ol (Mg)	4.56	3.17	3.72	2.56	1.39	3.56	0.00
Ol (Fe)	4.38	3.12	3.17	2.51	1.11	3.16	0.00

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WHOLE-ROCK ANALYSES

Sample#	8425.15	8204.15	8204.14	8204.13	8204.16A	8204.16B	8204.11
Traverse#	3.00	4.00	4.00	4.00	4.00	4.00	4.00
Along.Pos.	201.00	206.00	206.00	206.00	206.00	206.00	206.00
Across.Pos.	61.75	-59.60	-54.70	-38.95	-12.25	-12.25	-2.10
Thickness	148.50	137.50	137.50	137.50	137.50	137.50	137.50
Descript.	DYKE	SHOULDER?	DYKE	DYKE	DYKE	DYKELET	DYKE
SiO ₂	47.27	45.46	47.28	46.38	46.53	45.62	46.64
TiO ₂	2.31	3.51	2.06	3.23	3.27	4.06	3.29
Al ₂ O ₃	19.66	16.39	20.33	18.64	19.02	16.18	18.76
Fe ₂ O ₃ T	11.49	14.78	10.77	12.56	12.17	15.00	12.38
FeO	8.31	--	--	--	--	--	--
FeO(calc)	8.16	10.49	7.65	8.92	8.64	10.65	8.79
MgO	5.71	6.87	5.58	4.38	4.21	5.05	4.30
CaO	9.15	8.79	9.76	9.65	9.60	9.03	9.65
Na ₂ O	3.40	3.17	3.26	3.40	3.69	3.53	3.54
K ₂ O	0.97	1.11	0.91	1.06	1.02	1.04	0.98
P ₂ O ₅	0.51	0.76	0.41	0.75	0.69	0.94	0.68
MnO	0.14	0.19	0.13	0.16	0.15	0.19	0.16
S	0.01	0.04	0.01	0.00	0.01	0.01	0.02
LOI	--	0.31	0.99	0.68	--	--	0.95
Total	99.70	100.22	100.64	99.90	99.40	99.46	100.37
Zr	33.00	109.00	75.00	101.00	104.00	122.00	104.00
Y	24.00	26.00	15.00	21.00	21.00	26.00	23.00
Nb	9.00	16.00	12.00	16.00	13.00	24.00	17.00
Zn	91.00	119.00	61.00	96.00	92.00	100.00	83.00
Ba	774.00	894.00	647.00	814.00	763.00	973.00	808.00
Rb	13.00	9.00	13.00	11.00	9.00	17.00	5.00
Sr	982.00	827.00	1122.00	986.00	1023.00	875.00	994.00
V	126.00	258.00	156.00	269.00	241.00	307.00	242.00
Ni	43.00	67.00	64.00	26.00	31.00	32.00	19.00
Cr	51.31	51.92	--	--	--	--	--
Co	--	51.90	42.00	36.20	--	--	36.80
Ta	--	1.30	0.81	1.27	--	--	1.38
Sc	--	22.43	14.20	20.05	--	--	20.82
Hf	--	2.12	1.42	2.32	--	--	2.17
U	--	--	--	--	--	--	--
Th	--	1.06	0.79	1.24	--	--	1.22
La	--	21.00	15.00	20.90	--	--	20.90
Ce	--	48.90	32.90	50.00	--	--	49.50
Nd	--	28.00	16.40	27.80	--	--	27.10
Sm	--	5.56	3.63	5.52	--	--	5.75
Eu	--	2.49	2.04	2.37	--	--	2.51
Eu/Eu*	--	1.54	1.89	1.51	--	--	1.51
Tb	--	0.65	0.46	0.61	--	--	0.66
Yb	--	1.66	1.16	1.72	--	--	1.67
Lu	--	0.32	0.19	0.27	--	--	0.20
Qtz	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Or	5.75	6.57	5.40	6.31	6.06	6.18	5.82
Ab	28.47	26.06	27.00	28.48	28.34	29.34	29.06
An	35.63	27.25	38.29	32.73	32.52	25.37	32.60
Ne	0.21	0.43	0.37	0.27	1.66	0.38	0.58
Di	5.37	9.34	6.21	8.72	8.93	11.11	9.12
Opx	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ol	15.71	17.38	14.54	11.68	10.87	13.07	11.13
Mag	3.28	4.53	3.31	3.87	3.75	4.61	3.81
Ilm	4.40	6.67	3.93	6.18	6.25	7.75	6.28
Ap	1.21	1.80	0.97	1.79	1.64	2.24	1.62
Di (Ca)	2.74	4.78	3.18	4.42	4.54	5.64	4.63
Di (Mg)	1.55	2.75	1.84	2.33	2.41	2.97	2.46
Di (Fe)	1.07	1.81	1.19	1.96	1.98	2.50	2.03
Opx (Mg)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Opx (Fe)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ol (Mg)	8.91	10.08	8.48	6.07	5.70	6.78	5.83
Ol (Fe)	6.80	7.30	6.06	5.61	5.17	6.29	5.31

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Table A5.1

WHOLE-ROCK ANALYSES							
Sample#	8204.10	8204.09	8204.08	8204.07	8204.19	8203.05	8203.14
Traverse#	4.00	4.00	4.00	4.00	4.00	5.00	5.00
Along.Pos.	206.00	206.00	206.00	206.00	206.00	216.00	216.00
Across.Pos.	15.40	23.75	33.25	40.45	68.75	-76.70	-46.75
Thickness	137.50	137.50	137.50	137.50	137.50	109.00	109.00
Descript.	DYKE	DYKE	FEATH.	DYKELET	SAT.DYKE	SAT.DYKE	DYKE
SiO ₂	45.76	46.23	44.11	44.27	44.61	45.48	44.79
TiO ₂	3.24	2.92	3.06	3.83	3.68	3.33	4.20
Al ₂ O ₃	17.69	18.04	16.65	15.21	16.44	16.66	18.19
Fe ₂ O ₃ T	13.48	12.83	13.42	14.93	14.41	13.91	13.92
FeO	--	--	--	--	--	--	--
FeO(calc)	9.57	9.11	9.53	10.60	10.23	9.88	9.88
MgO	5.74	6.09	6.39	5.10	5.20	6.26	6.17
CaO	9.21	9.12	9.17	9.12	8.32	7.77	8.92
Na ₂ O	3.22	3.30	2.86	3.40	3.40	3.46	3.05
K ₂ O	1.01	1.16	1.01	1.26	1.45	1.33	0.71
P ₂ O ₅	0.63	0.66	0.68	0.95	0.87	0.75	0.40
MnO	0.17	0.16	0.17	0.21	0.18	0.18	0.17
S	0.01	0.01	0.03	0.02	0.18	0.02	0.01
LOI	0.52	0.78	3.22	2.20	1.98	2.32	0.40
Total	99.61	100.12	99.70	99.32	99.58	100.37	99.83
Zr	93.00	97.00	89.00	122.00	112.00	102.00	70.00
Y	23.00	18.00	20.00	30.00	25.00	23.00	12.00
Nb	14.00	14.00	13.00	20.00	17.00	14.00	15.00
Zn	34.00	34.00	65.00	119.00	142.00	221.00	85.00
Ba	817.00	739.00	825.00	1177.00	999.00	618.00	626.00
Rb	12.00	15.00	6.00	14.00	17.00	58.00	11.00
Sr	928.00	972.00	946.00	877.00	849.00	837.00	992.00
V	246.00	203.00	231.00	269.00	274.00	273.00	99.00
Ni	45.00	72.00	50.00	26.00	46.00	63.00	49.00
Cr	--	--	--	--	--	--	--
Co	45.60	46.10	51.70	43.10	43.70	43.80	52.30
Ta	1.33	1.17	1.18	1.67	1.60	1.28	0.99
Sc	20.68	18.24	18.88	25.24	24.07	21.23	20.58
Hf	2.41	2.42	2.27	2.93	2.37	2.07	1.66
U	--	--	--	--	--	--	--
Th	1.06	1.20	0.83	1.19	1.40	1.22	0.60
La	20.80	19.60	17.90	25.90	25.20	21.20	12.20
Ce	49.80	46.50	42.00	65.90	55.20	51.50	28.70
Nd	26.10	27.80	22.90	35.90	28.40	26.80	14.80
Sm	5.52	5.10	4.78	6.97	6.15	5.28	3.21
Eu	2.29	2.36	2.09	2.94	2.59	2.12	1.84
Eu/Eu*	1.43	1.76	1.59	1.40	1.38	1.37	2.14
Tb	0.65	0.45	0.49	0.90	--	0.63	0.30
Yb	1.72	1.54	1.52	2.06	1.86	1.66	1.04
Lu	0.27	0.24	0.24	0.36	0.32	0.31	0.17
Qtz	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Or	6.02	6.90	6.19	7.67	8.79	8.01	4.22
Ab	26.98	26.21	25.03	25.81	26.72	28.73	25.95
An	31.12	31.17	30.70	23.19	25.98	26.52	34.05
Ne	0.28	1.02	0.03	2.06	1.52	0.61	0.00
Di	8.88	8.18	9.68	14.01	8.67	6.38	6.38
Opx	0.00	0.00	0.00	0.00	0.00	0.00	1.91
Ol	14.88	15.65	16.46	12.79	14.54	17.18	14.25
Mag	4.16	3.95	4.25	4.70	4.52	4.34	4.28
Ilm	6.21	5.39	6.02	7.49	7.17	6.45	8.02
Ap	1.50	1.57	1.67	2.32	2.12	1.81	0.95
Di (Ca)	4.53	4.18	4.95	7.10	4.41	3.26	3.27
Di (Mg)	2.54	2.40	2.86	3.71	2.35	1.86	1.95
Di (Fe)	1.81	1.60	1.87	3.19	1.91	1.26	1.15
Opx (Mg)	0.00	0.00	0.00	0.00	0.00	0.00	1.20
Opx (Fe)	0.00	0.00	0.00	0.00	0.00	0.00	0.71
Ol (Mg)	8.03	9.02	9.56	6.57	7.67	9.84	8.62
Ol (Fe)	6.55	6.64	6.90	6.23	6.87	7.34	5.63

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Table A5.1

WHOLE-ROCK ANALYSES							
Samples	8203.15	8203.13	8203.11	8203.12	8430.04	8430.03B	8430.03A
Traverse	5.00	5.00	5.00	5.00	6.00	6.00	6.00
Along.Pos.	216.00	216.00	216.00	216.00	231.00	231.00	231.00
Across.Pos.	-43.50	-34.35	-10.60	-9.35	-101.00	-99.35	-99.35
Thickness	109.00	109.00	109.00	109.00	209.50	209.50	209.50
Descript.	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE
SiO ₂	46.15	46.90	43.74	44.71	47.67	44.89	47.62
TiO ₂	3.35	2.17	4.22	3.98	2.14	2.09	3.14
Al ₂ O ₃	19.40	19.10	10.65	11.25	20.63	16.15	20.51
Fe ₂ O ₃ T	13.09	12.38	21.35	20.49	10.92	16.32	10.14
FeO	9.20	--	14.89	14.34	8.35	12.50	6.70
FeO(calc)	9.29	8.79	15.16	14.55	7.75	11.59	7.20
MgO	6.28	6.60	4.62	4.40	5.56	10.54	3.09
CaO	8.88	9.21	8.54	8.59	9.79	8.10	10.43
Na ₂ O	3.06	3.05	3.00	3.21	3.47	2.69	3.74
K ₂ O	0.70	0.90	1.66	1.56	0.67	0.54	0.97
P ₂ O ₅	0.18	0.40	2.09	1.85	0.40	0.39	0.73
MnO	0.15	0.16	0.30	0.29	0.14	0.21	0.13
S	0.00	0.01	0.06	0.06	0.00	0.01	0.02
LOI	--	0.58	--	--	--	--	--
Total	100.23	100.48	98.57	98.79	100.46	100.54	99.77
Zr	65.00	71.00	169.00	175.00	76.00	65.00	116.00
Y	16.00	18.00	42.00	45.00	20.00	16.00	25.00
Nb	5.00	9.00	25.00	25.00	9.00	10.00	14.00
Zn	76.00	88.00	179.00	167.00	79.00	99.00	75.00
Ba	549.00	642.00	1440.00	1442.00	695.00	575.00	895.00
Rb	12.00	16.00	27.00	20.00	5.00	0.00	8.00
Sr	991.00	974.00	535.00	572.00	1085.00	807.00	1062.00
V	232.00	151.00	137.00	120.00	217.00	126.00	221.00
Ni	45.00	56.00	0.00	0.00	41.00	116.00	7.00
Cr	--	--	12.21	--	63.75	50.24	49.37
Co	51.90	47.00	44.40	42.90	--	--	--
Ta	0.67	0.79	2.22	2.89	--	--	--
Sc	17.67	14.07	37.28	38.27	--	--	--
Hf	1.05	1.45	4.08	4.36	--	--	--
U	--	--	--	--	--	--	--
Th	0.85	0.65	2.56	2.37	--	--	--
La	10.00	13.10	45.90	45.30	--	--	--
Ce	20.70	31.00	104.30	113.00	--	--	--
Nd	11.10	16.50	61.40	60.90	--	--	--
Sm	2.22	3.35	12.58	12.90	--	--	--
Eu	1.50	1.74	4.41	4.51	--	--	--
Eu/Eu ⁺	2.31	2.01	1.17	1.21	--	--	--
Tb	0.26	0.28	1.45	1.47	--	--	--
Yb	0.72	1.16	3.83	3.77	--	--	--
Lu	0.13	0.18	0.58	0.61	--	--	--
Qtz	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Or	4.13	5.32	9.96	9.34	3.94	3.17	5.74
Ab	25.83	25.83	25.77	27.51	27.64	22.14	30.72
An	37.05	35.81	10.85	11.83	38.56	30.24	36.40
Ne	0.00	0.00	0.00	0.00	0.86	0.27	0.54
Di	4.66	5.97	15.35	16.03	5.90	5.89	8.73
Opx	3.57	2.01	8.59	7.37	0.00	0.00	0.00
Ol	13.85	16.21	9.37	9.24	15.77	29.94	6.27
Mag	4.15	3.79	7.07	6.69	2.37	3.50	3.91
Ilm	6.35	4.13	8.13	7.66	4.05	3.95	5.98
Ap	0.42	0.95	5.02	4.44	0.94	0.92	1.73
Di (Ca)	2.39	3.05	7.64	7.98	3.00	3.01	4.47
Di (Mg)	1.42	1.77	3.11	3.21	1.63	1.71	2.56
Di (Fe)	0.85	1.15	4.59	4.84	1.26	1.17	1.71
Opx (Mg)	2.24	1.22	3.47	2.94	0.00	0.00	0.00
Opx (Fe)	1.33	0.79	5.12	4.44	0.00	0.00	0.00
Ol (Mg)	8.37	9.44	3.57	3.47	8.52	17.10	3.61
Ol (Fe)	5.48	6.77	5.80	5.77	7.25	12.84	2.66

(Continued on next page)

Table A5.1

WHOLE-ROCK ANALYSES							
Sample#	8430.05	8430.02	8430.01	8401.51	8401.50	8401.49	8401.48
Traverse#	6.00	6.00	6.00	7.00	7.00	7.00	7.00
Along.Pos.	231.00	231.00	231.00	243.00	243.00	243.00	243.00
Across.Pos.	-92.75	-90.35	-82.75	-137.75	-133.50	-117.25	-108.40
Thickness	209.50	209.50	209.50	209.50	209.50	209.50	209.50
Descript.	DYKE	DYKE	DYKE	HOSTROCK	HOSTROCK	HOSTROCK	HOSTROCK
SiO ₂	47.54	47.55	46.93	67.64	72.36	66.36	74.39
TiO ₂	2.14	2.00	3.01	0.38	0.07	0.47	0.04
Al ₂ O ₃	20.94	20.70	19.49	16.34	15.32	16.45	15.08
Fe ₂ O ₃ T	10.61	10.29	11.97	2.55	0.48	2.86	0.65
FeO	7.87	7.74	8.95	--	--	--	--
FeO(calc)	7.53	7.31	8.50	1.81	0.34	2.03	0.46
MgO	5.68	5.54	4.68	1.51	0.21	1.56	0.32
CaO	9.85	9.98	9.64	2.52	1.13	1.78	0.34
Na ₂ O	3.44	3.38	3.51	4.88	4.45	5.47	1.82
K ₂ O	0.64	0.67	0.92	3.54	5.22	3.31	5.47
P ₂ O ₅	0.36	0.48	0.63	0.20	0.01	0.23	0.01
MnO	0.13	0.13	0.15	0.05	0.01	0.05	0.01
S	0.00	0.00	0.02	0.00	0.00	0.00	0.01
LOI	--	--	--	--	--	--	--
Total	100.45	99.86	99.95	99.41	99.22	98.31	98.09
Zr	80.00	88.00	111.00	169.00	65.00	185.00	46.00
Y	16.00	19.00	24.00	10.00	3.00	9.00	2.00
Nb	4.00	11.00	16.00	2.00	0.00	5.00	1.00
Zn	68.00	73.00	87.00	60.00	35.00	117.00	28.00
Ba	672.00	687.00	843.00	1325.00	1586.00	1338.00	880.00
Rb	5.00	8.00	7.00	89.00	96.00	69.00	125.00
Sr	1084.00	1089.00	986.00	1116.00	751.00	841.00	217.00
V	154.00	133.00	173.00	26.00	5.00	43.00	7.00
Ni	45.00	53.00	23.00	11.00	0.00	10.00	0.00
Cr	83.63	9.59	55.85	6.57	35.53	11.99	19.35
Co	--	--	--	--	--	--	--
Ta	--	--	--	--	--	--	--
Sc	--	--	--	--	--	--	--
Hf	--	--	--	--	--	--	--
U	--	--	--	--	--	--	--
Th	--	--	--	--	--	--	--
La	--	--	--	--	--	--	--
Ce	--	--	--	--	--	--	--
Nd	--	--	--	--	--	--	--
Sm	--	--	--	--	--	--	--
Eu	--	--	--	--	--	--	--
Eu/Eu*	--	--	--	--	--	--	--
Tb	--	--	--	--	--	--	--
Yb	--	--	--	--	--	--	--
Lu	--	--	--	--	--	--	--
Qtz	0.00	0.00	0.00	17.65	23.78	15.49	42.19
Or	3.76	3.96	5.44	21.05	31.09	19.89	32.96
Ab	27.43	28.00	28.20	41.54	37.94	47.07	15.70
An	39.63	39.39	34.73	11.26	5.58	7.46	1.65
Ne	0.83	0.35	0.82	0.00	0.00	0.00	0.00
Di	5.46	5.77	7.42	0.00	0.00	0.00	0.00
Opx	0.00	0.00	0.00	6.14	0.98	6.54	1.51
Ol	15.32	15.16	13.27	0.00	0.00	0.00	0.00
Mag	2.69	2.45	2.94	0.78	0.15	0.89	0.20
Ilm	4.05	3.80	5.72	0.73	0.13	0.91	0.08
Ap	0.85	1.14	1.49	0.48	0.02	0.55	0.02
Di (Ca)	2.79	2.95	3.76	0.00	0.00	0.00	0.00
Di (Mg)	1.59	1.66	1.96	0.00	0.00	0.00	0.00
Di (Fe)	1.08	1.17	1.69	0.00	0.00	0.00	0.00
Opx (Mg)	0.00	0.00	0.00	3.78	0.53	3.95	0.81
Opx (Fe)	0.00	0.00	0.00	2.36	0.45	2.59	0.70
Ol (Mg)	9.76	8.52	6.80	0.00	0.00	0.00	0.00
Ol (Fe)	6.56	6.64	6.47	0.00	0.00	0.00	0.00

(Continued on next page)

Table A5.1

WHOLE-ROCK ANALYSES

Sample#	8401.52	8401.47	8401.01	8401.02	8401.03	8401.04	8401.05
Traverse#	7.00	7.00	7.00	7.00	7.00	7.00	7.00
Along.Pos.	243.00	243.00	243.00	243.00	243.00	243.00	243.00
Across.Pos.	-104.75	-104.75	-102.95	-101.00	-100.20	-98.00	-93.35
Thickness	209.50	209.50	209.50	209.50	209.50	209.50	209.50
Descript.	HOSTROCK	CONTAM.	DYKE	DYKE	DYKE	DYKE	DYKE
SiO ₂	61.41	51.20	46.19	47.12	46.38	46.46	47.82
TiO ₂	0.29	3.89	2.23	2.45	2.69	2.85	1.67
Al ₂ O ₃	20.43	13.41	19.14	19.32	18.17	18.98	21.13
Fe ₂ O ₃ T	2.86	13.63	13.14	12.01	13.20	12.66	10.05
FeO	--	6.90	10.59	8.60	9.93	9.80	9.06
FeO(calc)	2.03	9.68	9.33	8.53	9.37	8.99	7.14
MgO	1.94	3.92	7.63	5.92	6.25	5.30	5.80
CaO	5.72	7.46	8.76	9.32	9.15	9.44	9.70
Na ₂ O	5.06	3.19	3.03	3.33	3.16	3.46	3.53
K ₂ O	1.73	1.58	0.59	0.85	0.92	0.80	0.60
P ₂ O ₅	0.21	1.39	0.25	0.53	0.65	0.63	0.23
MnO	0.04	0.15	0.16	0.15	0.16	0.16	0.12
S	0.01	0.06	0.00	0.03	0.03	0.02	0.01
LOI	--	--	--	--	--	--	--
Total	99.42	99.11	99.94	100.07	99.65	99.67	99.76
Zr	151.00	98.00	56.00	88.00	96.00	91.00	68.00
Y	10.00	22.00	13.00	21.00	22.00	22.00	17.00
Nb	0.00	4.00	7.00	10.00	15.00	12.00	7.00
Zn	63.20	126.00	74.00	82.00	96.00	105.00	113.00
Ba	1360.00	682.00	515.00	685.00	728.00	671.00	578.00
Rb	31.00	34.00	5.00	10.00	12.00	7.00	5.00
Sr	2065.00	736.00	983.00	995.00	961.00	990.00	1102.00
V	24.00	347.00	--	--	--	--	--
Ni	23.00	6.00	62.00	44.00	48.00	33.00	52.00
Cr	29.76	21.61	--	--	--	--	--
Co	--	--	--	--	--	--	--
Ta	--	--	--	--	--	--	--
Sc	--	--	--	--	--	--	--
Hf	--	--	--	--	--	--	--
U	--	--	--	--	--	--	--
Th	--	--	--	--	--	--	--
La	--	--	--	--	--	--	--
Ce	--	--	--	--	--	--	--
Nd	--	--	--	--	--	--	--
Sm	--	--	--	--	--	--	--
Eu	--	--	--	--	--	--	--
Eu/Eu ⁺	--	--	--	--	--	--	--
Tb	--	--	--	--	--	--	--
Yb	--	--	--	--	--	--	--
Lu	--	--	--	--	--	--	--
Qtz	9.54	10.29	0.00	0.00	0.00	0.00	0.00
Or	10.28	9.43	3.49	5.02	5.46	4.74	3.55
Ab	43.04	27.25	24.97	28.16	26.83	27.33	27.00
An	27.20	17.77	36.91	35.25	32.80	34.01	40.14
Ne	0.00	0.00	0.36	0.00	0.00	1.11	1.59
Di	0.00	8.25	4.06	6.14	6.98	7.31	5.42
Opx	7.70	7.58	0.00	0.54	0.61	0.00	0.00
Ol	0.00	0.00	23.40	15.46	17.52	16.03	17.00
Mag	0.88	8.73	1.99	3.55	3.15	2.57	1.59
Ilm	0.55	7.46	4.24	4.65	5.13	5.43	3.18
Ap	0.50	3.32	0.59	1.25	1.54	1.50	0.54
Di (Ca)	0.00	4.35	2.06	3.14	3.55	3.70	2.75
Di (Mg)	0.00	3.35	1.12	1.79	1.92	1.88	1.49
Di (Fe)	0.00	7.55	0.88	1.21	1.51	1.73	1.17
Opx (Mg)	4.86	6.51	0.00	0.32	0.34	0.00	0.00
Opx (Fe)	2.84	1.07	0.00	0.22	0.27	0.00	0.00
Ol (Mg)	0.00	0.00	12.54	8.85	9.37	7.96	9.10
Ol (Fe)	0.00	0.00	10.86	6.61	8.16	8.06	7.89

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Table A5.1

WHOLE-ROCK ANALYSES							
Sample#	8401.06	8401.07	8401.08	8401.09	8401.10	8401.11	8401.12
Traverse#	7.00	7.00	7.00	7.00	7.00	7.00	7.00
Along.Pos.	243.00	243.00	243.00	243.00	243.00	243.00	243.00
Across.Pos.	-88.75	-77.10	-71.00	-60.85	-52.85	-46.15	-37.35
Thickness	209.50	209.50	209.50	209.50	209.50	209.50	209.50
Descript.	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE
SiO ₂	47.33	43.27	49.26	47.24	46.53	46.48	47.72
TiO ₂	3.31	4.60	2.84	3.25	3.50	3.53	3.33
Al ₂ O ₃	19.50	14.57	13.72	13.13	12.68	12.79	13.56
Fe ₂ O ₃ T	11.31	16.25	16.14	17.77	18.32	18.22	16.95
FeO	7.78	11.15	10.66	12.25	12.95	13.20	12.26
FeO(calc)	2.03	11.54	11.46	12.62	13.01	12.94	12.03
MgO	3.39	4.87	2.39	2.79	3.11	3.25	3.04
CaO	10.04	10.81	6.89	7.86	8.21	9.32	9.13
Na ₂ O	3.54	3.15	4.41	4.02	3.86	3.89	4.23
K ₂ O	1.02	0.81	2.34	1.93	1.87	1.76	1.85
P ₂ O ₅	0.71	2.01	1.34	1.74	1.85	2.00	1.83
MnO	0.14	0.19	0.23	0.25	0.26	0.26	0.23
S	0.03	0.01	0.09	0.13	0.13	0.13	0.04
LOI	--	--	--	--	--	--	--
Total	99.45	99.30	98.45	98.75	98.88	99.16	99.55
Zr	110.00	86.00	215.00	186.00	200.00	190.00	196.00
Y	22.00	29.00	45.00	42.00	43.00	46.00	40.00
Nb	15.00	15.00	32.00	33.00	28.00	32.00	26.00
Zn	30.00	99.00	149.00	165.00	161.00	157.00	154.00
Ba	786.00	637.00	1925.00	1736.00	1568.00	1528.00	1610.00
Rb	12.00	7.00	31.00	20.00	24.00	25.00	24.00
Sr	1004.00	782.00	652.00	694.00	658.00	688.00	727.00
V	--	--	--	--	--	--	--
Ni	6.00	5.00	0.00	0.00	0.00	0.00	0.00
Cr	--	--	--	--	--	--	--
Co	--	--	--	--	--	--	--
Ta	--	--	--	--	--	--	--
Sc	--	--	--	--	--	--	--
Hf	--	--	--	--	--	--	--
U	--	--	--	--	--	--	--
Th	--	--	--	--	--	--	--
La	--	--	--	--	--	--	--
Ce	--	--	--	--	--	--	--
Nd	--	--	--	--	--	--	--
Sm	--	--	--	--	--	--	--
Eu	--	--	--	--	--	--	--
Eu/Eu*	--	--	--	--	--	--	--
Tb	--	--	--	--	--	--	--
Yb	--	--	--	--	--	--	--
Lu	--	--	--	--	--	--	--
Qtz	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Or	6.06	4.82	14.05	11.57	11.19	10.50	10.99
Ab	30.12	26.84	37.93	34.49	33.07	33.24	35.68
An	34.51	23.39	10.91	12.25	11.90	12.36	12.61
Ne	0.00	0.00	0.00	0.00	0.00	0.00	0.16
Di	8.98	14.31	12.61	13.37	14.49	13.66	13.47
Opx	1.53	1.14	3.28	3.67	2.35	2.38	0.00
Ol	6.93	10.37	6.24	8.21	10.16	11.21	11.64
Mag	3.83	5.63	6.33	6.11	5.77	5.20	4.85
Ilm	6.32	8.80	5.48	6.26	6.73	6.77	6.36
Ap	1.69	4.79	3.23	4.18	4.44	4.78	4.36
Di (Ca)	4.56	7.27	6.22	6.59	7.15	6.74	6.65
Di (Mg)	2.43	3.85	2.15	2.23	2.47	2.33	2.32
Di (Fe)	1.98	3.19	4.24	4.55	4.87	4.59	4.50
Opx (Mg)	0.85	0.63	1.10	1.21	0.79	0.80	0.00
Opx (Fe)	0.69	0.52	2.18	2.46	1.56	1.58	0.00
Ol (Mg)	3.65	5.42	1.96	2.53	3.21	3.53	3.71
Ol (Fe)	3.28	4.95	4.28	5.68	6.96	7.68	7.93

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Table A5.1

WHOLE-ROCK ANALYSES							
Sample#	8401.13	8401.31	8401.14	8401.15	8401.33	8401.34	8401.16
Traverse#	7.00	7.00	7.00	7.00	7.00	7.00	7.00
Along.Pos.	243.00	243.00	243.00	243.00	243.00	243.00	243.00
Across.Pos.	-28.60	-20.60	-11.80	-6.80	-1.25	11.50	15.55
Thickness	209.50	209.50	209.50	209.50	209.50	209.50	209.50
Descript.	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE
SiO ₂	48.37	48.48	47.39	47.53	44.43	44.69	46.62
TiO ₂	3.02	3.22	3.22	3.23	3.99	3.91	3.52
Al ₂ O ₃	14.20	14.30	13.92	13.75	11.78	11.64	13.01
Fe ₂ O ₃ T	15.63	16.05	16.06	16.96	19.84	20.11	17.82
FeO	11.17	11.10	11.29	11.89	14.55	14.33	12.50
FeO(calc)	11.10	11.10	11.40	12.04	14.09	14.28	12.65
MgO	2.61	2.79	2.79	2.91	3.68	3.71	3.12
CaO	7.73	8.01	7.86	8.22	8.83	8.76	8.22
Na ₂ O	4.46	4.35	4.19	4.22	3.55	3.57	3.99
K ₂ O	1.93	1.91	1.87	1.82	1.62	1.68	1.95
P ₂ O ₅	1.67	1.89	1.70	1.70	2.31	2.14	1.89
MnO	0.21	0.22	0.22	0.23	0.27	0.28	0.24
S	0.11	0.03	0.12	0.04	0.17	0.14	0.10
LOI	--	--	--	--	--	--	--
Total	98.70	100.01	98.08	99.29	98.75	99.04	99.09
Zr	187.00	175.00	186.00	191.00	169.00	176.00	185.00
Y	42.00	44.00	41.00	45.00	45.00	45.00	41.00
Nb	25.00	23.00	27.00	29.00	29.00	27.00	26.00
Zn	134.00	163.00	139.00	146.00	167.00	167.00	178.00
Ba	1705.00	1764.00	1582.00	1575.00	1431.00	1393.00	1574.00
Rb	20.00	22.00	24.00	25.00	22.00	20.00	26.00
Sr	764.00	769.00	766.00	753.00	647.00	605.00	713.00
V	--	--	--	--	--	--	--
Ni	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr	--	--	--	--	--	--	--
Co	--	--	--	--	--	--	--
Ta	--	--	--	--	--	--	--
Sc	--	--	--	--	--	--	--
Hf	--	--	--	--	--	--	--
U	--	--	--	--	--	--	--
Th	--	--	--	--	--	--	--
La	--	--	--	--	--	--	--
Ce	--	--	--	--	--	--	--
Nd	--	--	--	--	--	--	--
Sm	--	--	--	--	--	--	--
Eu	--	--	--	--	--	--	--
Eu/Eu*	--	--	--	--	--	--	--
Tb	--	--	--	--	--	--	--
Yb	--	--	--	--	--	--	--
Lu	--	--	--	--	--	--	--
Qtz	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Or	11.57	11.29	11.28	10.83	9.70	10.04	11.64
Ab	37.79	36.81	36.19	35.22	30.44	30.54	33.82
An	13.22	13.86	13.94	13.30	11.58	10.90	11.95
Ne	0.26	0.00	0.00	0.41	0.00	0.00	0.15
Di	12.39	11.43	12.29	14.05	14.83	15.98	14.17
Opx	0.00	2.34	1.33	0.00	1.17	0.65	0.00
Ol	10.30	8.40	9.52	10.57	13.79	13.24	11.34
Mag	4.73	5.39	5.20	5.47	5.39	6.13	5.75
Ilm	5.82	6.12	6.24	6.18	7.68	7.51	6.75
Ap	4.01	4.48	4.11	4.06	5.54	5.12	4.52
Di (Ca)	6.11	5.66	6.07	6.94	7.32	7.90	7.01
Di (Mg)	2.07	2.07	2.17	2.44	2.57	2.85	2.52
Di (Fe)	4.22	3.70	4.04	4.67	4.94	5.22	4.65
Opx (Mg)	0.00	0.84	0.46	0.00	0.40	0.23	0.00
Opx (Fe)	0.00	1.50	0.86	0.00	0.77	0.42	0.00
Ol (Mg)	3.17	2.83	3.12	3.40	4.43	4.39	3.74
Ol (Fe)	7.13	5.57	6.40	7.16	9.37	8.85	7.60

(Continued on next page)

Table A5.1

WHOLE-ROCK ANALYSES							
Sample#	8401.17	8401.35	8401.18	8401.19	8401.20	8401.21	8401.22
Traverse#	7.00	7.00	7.00	7.00	7.00	7.00	7.00
Along.Pos.	243.00	243.00	243.00	243.00	243.00	243.00	243.00
Across.Pos.	19.30	25.05	25.65	31.55	36.75	44.15	63.50
Thickness	209.50	209.50	209.50	209.50	209.50	209.50	209.50
Descript.	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE
SiO ₂	46.41	43.87	44.10	44.58	46.53	45.07	46.39
TiO ₂	3.64	4.10	4.05	4.04	3.52	3.90	4.12
Al ₂ O ₃	12.63	10.93	11.15	10.87	12.14	11.48	12.97
Fe ₂ O ₃ T	14.71	21.62	21.05	21.66	18.69	20.30	16.96
FeO	12.80	15.21	14.96	16.20	13.80	14.41	11.30
FeO(calc)	12.93	15.35	14.95	15.38	13.27	14.41	12.04
MgO	3.33	4.01	3.95	4.03	3.28	3.66	3.94
CaO	8.39	8.41	8.38	8.28	8.07	8.63	9.13
Na ₂ O	3.84	3.41	3.35	3.45	3.74	3.54	3.49
K ₂ O	1.82	1.70	1.73	1.75	1.92	1.70	1.63
P ₂ O ₅	1.98	2.08	2.03	1.84	1.72	2.19	1.43
MnO	0.26	0.30	0.29	0.30	0.26	0.29	0.23
S	0.15	0.05	0.05	0.12	0.15	0.10	0.06
LOI	--	--	--	--	--	--	--
Total	99.24	98.79	98.46	99.12	98.48	99.26	99.09
Zr	184.00	180.00	177.00	199.00	206.00	187.00	165.00
Y	46.00	43.00	43.00	45.00	50.00	48.00	38.00
Nb	29.00	26.00	30.00	32.00	32.00	32.00	23.00
Zn	148.00	187.00	157.00	174.00	166.00	182.00	156.00
Ba	1512.00	1408.00	1403.00	1442.00	1613.00	1446.00	1495.00
Rb	22.00	18.00	27.00	24.00	28.00	21.00	20.00
Sr	665.00	572.00	573.00	532.00	638.00	606.00	643.00
V	--	--	--	--	--	--	--
NI	0.00	0.00	0.00	0.00	0.00	0.	0.00
Cr	--	--	--	--	--	--	--
Co	--	--	--	--	--	--	--
Ta	--	--	--	--	--	--	--
Sc	--	--	--	--	--	--	--
Hf	--	--	--	--	--	--	--
U	--	--	--	--	--	--	--
Th	--	--	--	--	--	--	--
La	--	--	--	--	--	--	--
Ce	--	--	--	--	--	--	--
Nd	--	--	--	--	--	--	--
Sm	--	--	--	--	--	--	--
Eu	--	--	--	--	--	--	--
Eu/Eu ⁺	--	--	--	--	--	--	--
Tb	--	--	--	--	--	--	--
Yb	--	--	--	--	--	--	--
Lu	--	--	--	--	--	--	--
Qtz	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Or	10.85	10.17	10.38	10.44	11.54	10.13	9.72
Ab	32.79	29.22	28.79	28.89	32.18	30.21	29.82
An	11.96	9.62	10.45	9.10	10.85	10.50	15.06
Ne	0.00	0.00	0.00	0.32	0.00	0.00	0.00
Di	14.34	15.94	15.47	17.17	15.65	15.43	17.64
Opx	2.82	1.37	3.00	0.00	2.33	4.01	4.67
Ol	9.80	14.00	12.79	16.66	11.66	10.87	5.40
Mag	5.83	6.93	6.52	5.36	4.94	6.27	6.44
Hm	6.98	7.89	7.82	7.75	6.80	7.47	7.90
Ap	4.73	4.99	4.88	4.40	4.14	5.23	3.42
Di (Ca)	7.10	7.89	7.65	8.46	7.70	7.63	8.88
Di (Mg)	2.61	2.89	2.80	2.85	2.55	2.72	4.19
Di (Fe)	4.63	5.16	5.02	5.86	5.39	5.08	4.58
Opx (Mg)	1.02	0.49	1.07	0.00	0.75	1.40	2.23
Opx (Fe)	1.80	0.88	1.93	0.00	1.58	2.61	2.44
Ol (Mg)	3.32	4.72	4.29	5.11	3.51	3.55	2.45
Ol (Fe)	6.48	9.28	8.50	11.56	8.16	7.31	2.95

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Table A5.1

WHOLE-ROCK ANALYSES							
Sample#	8401.23	8401.24	8401.39	8401.54	8401.53	8401.55	8401.40
Traverse#	7.00	7.00	7.00	7.00	7.00	7.00	7.00
Along.Pos.	243.00	243.00	243.00	243.00	243.00	243.00	243.00
Across.Pos.	67.35	78.50	84.30	88.25	88.85	89.75	90.60
Thickness	209.50	209.50	209.50	209.50	209.50	209.50	209.50
Descript.	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE
SiO ₂	43.30	43.78	45.04	45.19	46.04	47.66	47.39
TiO ₂	5.69	5.72	5.12	2.97	2.38	1.54	1.84
Al ₂ O ₃	13.14	14.82	16.37	15.30	18.02	20.48	19.69
Fe ₂ O ₃ T	19.35	17.45	15.63	16.18	13.42	10.68	11.71
FeO	13.27	13.30	11.50	12.26	10.62	8.39	8.70
FeO(calc)	13.03	12.39	11.10	11.49	9.53	7.58	8.31
MgO	4.63	5.86	5.48	8.55	7.29	6.59	7.38
CaO	9.08	7.95	8.36	7.75	9.02	9.52	9.28
Na ₂ O	3.06	3.43	3.39	3.12	3.09	3.27	3.21
K ₂ O	1.25	1.03	1.05	0.94	0.69	0.62	0.61
P ₂ O ₅	1.15	0.78	0.71	0.70	0.46	0.25	0.39
MnO	0.22	0.21	0.19	0.19	0.16	0.13	0.15
S	0.03	0.03	0.02	0.03	0.02	0.01	0.01
LOI	--	--	--	--	--	--	--
Total	98.72	99.58	100.08	99.56	99.41	99.82	100.39
Zr	137.00	116.00	113.00	100.00	77.00	67.00	79.00
Y	32.00	26.00	23.00	24.00	20.00	13.00	18.00
Nb	22.00	21.00	18.00	16.00	10.00	11.00	9.00
Zn	134.00	121.00	104.00	113.00	104.00	76.00	83.00
Ba	369.00	716.00	904.00	719.00	565.00	578.00	656.00
Rb	15.00	15.00	9.00	12.00	7.00	6.00	3.00
Sr	628.00	726.00	798.00	756.00	929.00	1078.00	1017.00
V	--	--	301.00	--	--	--	119.00
Ni	0.00	18.00	26.00	69.00	68.00	65.00	80.00
Cr	--	--	57.91	--	--	--	39.89
Co	--	--	--	--	--	--	--
Ta	--	--	--	--	--	--	--
Sc	--	--	--	--	--	--	--
Hf	--	--	--	--	--	--	--
U	--	--	--	--	--	--	--
Th	--	--	--	--	--	--	--
La	--	--	--	--	--	--	--
Ce	--	--	--	--	--	--	--
Nd	--	--	--	--	--	--	--
Sm	--	--	--	--	--	--	--
Eu	--	--	--	--	--	--	--
Eu/Eu*	--	--	--	--	--	--	--
Tb	--	--	--	--	--	--	--
Yb	--	--	--	--	--	--	--
Lu	--	--	--	--	--	--	--
Qtz	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Or	7.48	6.11	6.20	5.58	4.10	3.67	3.59
Ab	25.91	27.01	28.66	26.07	25.35	26.85	26.66
An	17.31	22.10	26.34	25.09	33.46	39.45	37.38
Ne	1.57	1.16	0.00	0.24	0.52	0.47	0.21
Di	17.19	10.23	8.60	7.33	7.01	5.11	4.85
Opx	0.00	0.00	0.06	0.00	0.00	0.00	0.00
Ol	11.59	16.78	14.65	24.66	21.57	18.97	19.98
Mag	5.29	3.89	4.13	3.72	2.36	1.97	2.95
Ilm	10.95	10.91	9.72	5.67	4.55	2.93	3.48
Ap	2.76	1.85	1.68	1.67	1.09	0.59	0.92
Di (Ca)	8.65	5.18	4.38	3.74	3.57	2.60	2.48
Di (Mg)	4.11	2.65	2.37	2.06	1.92	1.45	1.45
Di (Fe)	4.42	2.39	1.85	1.53	1.53	1.06	0.91
Opx (Mg)	0.00	0.00	0.03	0.00	0.00	0.00	0.00
Opx (Fe)	0.00	0.00	0.02	0.00	0.00	0.00	0.00
Ol (Mg)	5.31	8.41	7.87	13.55	11.46	10.51	11.81
Ol (Fe)	6.29	8.36	6.78	11.11	10.11	8.46	8.17

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Table A5.1

WHOLE-ROCK ANALYSES							
Sample#	8401.46	8205.04	8205.06	8205.03	8205.01	8205.02	8403.02
Traverse#	7.00	8.00	8.00	8.00	8.00	8.00	9.00
Along.Pos.	243.00	290.00	290.00	290.00	290.00	290.00	320.00
Across.Pos.	104.70	42.75	103.90	104.00	106.85	107.75	-99.00
Thickness	209.50	220.00	220.00	220.00	220.00	220.00	186.00
Descript.	CHIL.MAR	DYKE	HETER.	DYKE	DYKE	DYKE	SAT.DYKE
SiO ₂	44.74	48.67	44.36	46.50	46.15	46.84	45.27
TiO ₂	3.48	2.90	6.54	3.28	3.28	2.99	3.52
Al ₂ O ₃	16.90	13.07	12.92	18.47	17.68	18.81	16.52
Fe ₂ O ₃ T	15.10	17.43	15.70	13.02	13.66	12.93	14.71
FeO	3.44	--	--	--	--	--	9.13
FeO(calc)	10.72	12.38	11.15	9.24	9.70	9.18	10.44
MgO	4.70	2.83	5.80	5.15	5.48	5.60	6.24
CaO	9.14	7.86	11.04	9.48	9.16	9.29	9.85
Na ₂ O	2.92	3.38	3.03	3.64	3.31	3.41	2.59
K ₂ O	0.64	1.44	0.84	0.86	0.94	0.82	0.21
P ₂ O ₅	0.63	1.45	0.44	0.62	0.69	0.64	0.91
MnO	0.13	0.25	0.20	0.16	0.17	0.16	0.21
S	0.05	0.07	0.02	0.01	0.03	0.01	0.00
LOI	--	2.24	0.33	0.20	0.16	0.25	--
Total	99.54	100.21	99.98	100.36	99.63	100.73	99.01
Zr	81.00	87.00	99.00	100.00	107.00	91.00	96.00
Y	23.00	29.00	23.00	20.00	24.00	21.00	28.00
Nb	13.00	20.00	17.00	16.00	17.00	16.00	14.00
Zn	109.00	159.00	106.00	107.00	95.00	102.00	133.00
Ba	~24.00	928.00	671.00	773.00	875.00	760.00	572.00
Rb	7.00	54.00	13.00	8.00	7.00	9.00	0.00
Sr	878.00	746.00	624.00	973.00	906.00	1006.00	736.00
V	--	26.00	824.00	253.00	264.00	238.00	273.00
Ni	60.00	0.00	28.00	38.00	28.00	40.00	42.00
Cr	--	--	--	--	60.36	--	34.52
Co	--	28.00	46.40	42.10	45.00	46.60	--
Ta	--	1.54	1.50	1.11	1.30	1.15	--
Sc	--	29.99	55.99	20.75	21.07	19.20	--
Hf	--	2.12	2.26	2.05	2.23	1.88	--
U	--	0.65	--	--	--	--	--
Th	--	2.78	0.92	0.76	1.08	0.98	--
La	--	33.30	16.50	19.00	20.90	18.40	--
Ce	--	86.00	40.10	43.30	48.50	41.30	--
Nd	--	49.00	20.90	20.30	25.90	23.10	--
Sm	--	9.73	5.13	4.91	5.26	4.71	--
Eu	--	4.25	2.27	2.22	2.40	2.28	--
Eu/Eu*	--	1.52	1.48	1.49	1.57	1.62	--
Tb	--	1.10	0.66	0.66	0.62	0.61	--
Yb	--	2.25	2.02	1.57	1.71	1.35	--
Lu	--	--	0.28	0.26	0.28	0.28	--
Qtz	0.00	2.45	0.00	0.00	0.00	0.00	0.29
Or	3.80	8.69	4.98	5.07	5.59	4.82	1.25
Ab	24.83	29.21	22.78	27.89	28.16	28.72	22.13
An	31.28	16.59	19.24	31.47	30.78	33.44	23.16
Ne	0.00	0.00	1.60	1.55	0.00	0.00	0.00
Di	8.14	11.52	26.60	9.38	8.52	6.77	8.25
Opx	8.48	17.03	0.00	0.00	1.11	0.81	19.35
Ol	7.03	0.00	6.48	13.00	13.77	14.37	0.00
Mag	8.34	5.44	4.82	3.98	4.20	3.94	6.68
Ilm	6.64	5.63	12.47	6.22	6.26	5.65	6.75
Ap	1.50	3.51	1.04	1.47	1.64	1.51	2.18
Di (Ca)	4.24	5.67	13.72	4.78	4.34	3.45	4.26
Di (Mg)	2.95	1.84	8.56	2.63	2.38	1.93	2.68
Di (Fe)	0.95	4.02	4.33	1.97	1.80	1.38	1.31
Opx (Mg)	6.42	5.36	0.00	0.00	0.63	0.47	13.01
Opx (Fe)	2.06	11.68	0.00	0.00	0.48	0.34	6.34
Ol (Mg)	5.19	0.00	4.16	7.13	7.51	8.04	0.00
Ol (Fe)	1.84	0.00	2.32	5.87	6.26	6.33	0.00

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Table A5.1

WHOLE-ROCK ANALYSES							
Sample#	8403.01	8404.23	8404.22	8404.21	404.24	8404.20	8404.19
Traverse#	9.00	10.00	10.00	10.00	10.00	10.00	10.00
Along.Pos.	320.00	330.00	330.00	330.00	330.00	330.00	330.00
Across.Pos.	-99.00	-98.03	-97.13	-96.26	-95.18	-95.05	-94.76
Thickness	186.00	186.55	186.55	186.55	186.55	186.55	186.55
Descript.	SAT.DYKE	HOSTROCK	HOSTROCK	HOSTROCK	HOSTROCK	HOSTROCK	HOSTROCK
SiO ₂	45.62	51.96	53.24	52.66	53.23	52.43	51.10
TiO ₂	3.33	0.89	1.26	0.93	0.82	0.88	0.79
Al ₂ O ₃	17.17	14.41	13.59	14.48	14.56	14.76	13.85
Fe ₂ O ₃ T	14.18	12.85	15.43	13.58	13.38	13.13	11.92
FeO	8.50	--	--	--	--	--	--
FeO(calc)	10.07	9.12	10.96	9.64	9.50	9.32	8.46
MgO	6.12	5.85	4.20	5.47	7.43	6.95	5.44
CaO	9.62	11.90	10.61	11.65	9.73	9.92	13.98
Na ₂ O	2.84	2.03	1.12	1.50	1.88	2.48	1.89
K ₂ O	0.38	0.13	0.06	0.07	0.06	0.07	0.41
P ₂ O ₅	0.78	0.00	0.00	0.00	0.00	0.00	0.00
MnO	0.19	0.18	0.19	0.19	0.20	0.20	0.18
S	0.00	0.01	0.14	0.01	0.01	0.01	0.06
LOI	--	--	--	--	--	--	--
Total	99.28	99.19	98.62	99.47	100.24	99.79	98.68
Zr	110.00	49.00	72.00	49.00	40.00	47.00	41.00
Y	27.00	29.00	35.00	27.00	27.00	30.00	22.00
Nb	16.00	0.00	0.00	0.00	0.00	0.00	0.00
Zn	105.00	79.00	92.00	84.00	97.00	84.00	47.00
Ba	708.00	60.00	57.00	47.00	73.00	77.00	114.00
Rb	1.00	0.00	0.00	0.00	0.00	0.00	7.00
Sr	783.00	115.00	107.00	115.00	74.00	108.00	193.00
V	221.00	315.00	368.00	333.00	315.00	311.00	281.00
Ni	53.00	33.00	15.00	31.00	39.00	34.00	31.00
Cr	60.37	71.60	0.00	37.92	60.60	71.97	68.77
Co	--	--	--	--	--	--	--
Ta	--	--	--	--	--	--	--
Sc	--	--	--	--	--	--	--
Hf	--	--	--	--	--	--	--
U	--	--	--	--	--	--	--
Th	--	--	--	--	--	--	--
La	--	--	--	--	--	--	--
Ce	--	--	--	--	--	--	--
Nd	--	--	--	--	--	--	--
Sm	--	--	--	--	--	--	--
Eu	--	--	--	--	--	--	--
Eu/Eu*	--	--	--	--	--	--	--
Tb	--	--	--	--	--	--	--
Yb	--	--	--	--	--	--	--
Lu	--	--	--	--	--	--	--
Qtz	0.00	5.70	15.06	9.60	7.40	4.25	3.75
Or	2.26	0.77	0.35	0.41	0.35	0.41	2.45
Ab	24.20	17.31	9.62	12.76	15.87	21.03	16.21
An	33.22	30.07	32.37	32.75	31.04	29.00	28.49
Ne	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Di	7.84	24.29	17.68	21.01	14.03	16.68	34.51
Opx	15.31	16.18	17.68	17.51	25.67	22.93	9.36
Ol	2.07	0.00	0.00	0.00	0.00	0.00	0.00
Mag	6.91	3.96	4.79	4.18	4.08	4.02	3.70
Ilm	6.37	1.70	2.43	1.78	1.55	1.67	1.52
Ap	1.86	0.00	0.00	0.00	0.00	0.00	0.00
Di (Ca)	4.06	12.29	8.80	10.59	7.14	8.48	17.46
Di (Mg)	2.64	6.26	3.55	5.11	3.91	4.57	8.87
Di (Fe)	1.14	5.74	5.33	5.31	2.98	3.63	8.18
Opx (Mg)	10.71	8.44	7.07	8.59	14.56	12.78	4.87
Opx (Fe)	4.60	7.74	10.61	8.92	11.11	10.15	4.49
Ol (Mg)	1.40	0.00	0.00	0.00	0.00	0.00	0.00
Ol (Fe)	0.66	0.00	0.00	0.00	0.00	0.00	0.00

(Continued on next page)

Table A5.1

WHOLE-ROCK ANALYSES							
Sample#	8404.18	8404.17	8404.16	8404.15	8202.08	8202.05	8202.02
Traverse#	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Along.Pos.	330.00	330.00	330.00	330.00	330.00	330.00	330.00
Across.Pos.	-94.42	-93.99	-93.63	-93.28	-93.28	-93.28	-93.28
Thickness	186.55	186.55	186.55	186.55	186.55	186.55	186.55
Descript.	HOSTROCK	HOSTROCK	HOSTROCK	CONTAM.	VOLATILE?	VOLATILE?	VOLATILE?
SiO ₂	53.13	50.16	50.76	48.34	45.42	44.96	47.59
TiO ₂	0.92	0.80	0.97	2.28	3.68	2.72	3.78
Al ₂ O ₃	14.11	14.88	14.38	14.20	16.54	16.95	16.76
Fe ₂ O ₃ T	13.90	13.67	12.64	11.62	14.87	13.40	13.46
FeO	--	--	--	--	--	--	--
FeO(calc)	9.87	9.71	8.97	8.25	10.56	9.51	9.56
MgO	7.22	8.60	8.16	7.88	5.85	6.97	5.77
CaO	7.97	10.85	11.09	11.71	8.54	8.68	8.01
Na ₂ O	1.30	1.78	2.24	2.51	2.97	2.78	3.24
K ₂ O	0.05	0.05	0.10	0.27	0.66	0.80	0.58
P ₂ O ₅	0.00	0.00	0.05	0.40	0.72	0.51	0.19
MnO	0.21	0.22	0.22	0.19	0.19	0.19	0.18
S	0.02	0.01	0.02	0.03	0.06	0.02	0.01
LOI	--	--	--	--	1.53	3.33	1.67
Total	99.73	99.94	99.63	98.51	99.85	100.25	100.18
Zr	43.00	28.00	30.00	75.00	78.00	66.00	87.00
Y	27.00	26.00	20.00	28.00	19.00	19.00	16.00
Nb	0.00	0.00	1.00	5.00	13.00	11.00	15.00
Zn	34.00	96.00	92.00	86.00	94.00	78.00	79.00
Ba	43.00	75.00	90.00	445.00	601.00	640.00	537.00
Rb	0.00	0.00	0.00	0.00	9.00	17.00	5.00
Sr	140.00	120.00	137.00	431.00	754.00	572.00	714.00
V	314.00	321.00	257.00	209.00	313.00	234.00	261.00
Ni	35.00	41.00	41.00	40.00	36.00	69.00	47.00
Cr	72.69	116.04	167.01	183.49	--	--	--
Co	--	--	--	--	59.00	47.60	48.20
Ta	--	--	--	--	1.20	1.02	1.08
Sc	--	--	--	--	22.06	17.84	20.84
Hf	--	--	--	--	1.83	1.48	1.90
U	--	--	--	--	--	--	0.43
Th	--	--	--	--	1.05	0.59	1.38
La	--	--	--	--	15.80	--	11.50
Ce	--	--	--	--	37.20	36.00	27.10
Nd	--	--	--	--	21.60	--	14.30
Sm	--	--	--	--	4.61	--	2.95
Eu	--	--	--	--	2.04	1.84	1.67
Eu/Eu*	--	--	--	--	1.41	--	1.80
Tb	--	--	--	--	0.68	0.47	0.44
Yb	--	--	--	--	1.43	--	1.29
Lu	--	--	--	--	0.27	--	0.21
Qtz	10.31	1.54	1.18	0.00	0.00	0.00	0.00
Or	0.30	0.30	0.59	1.62	3.97	4.88	3.48
Ab	11.03	15.07	19.02	21.56	25.57	24.27	27.83
An	32.61	32.49	29.00	27.09	30.38	32.42	29.93
Ne	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Di	13.96	17.46	21.13	23.67	6.52	7.00	7.47
Opx	25.78	27.44	23.23	13.89	12.56	6.73	16.68
Ol	0.00	0.00	0.00	3.21	7.56	13.93	2.70
Mag	4.26	4.18	3.88	3.61	4.63	4.23	4.18
Ilm	1.75	1.52	1.85	4.40	7.11	5.33	7.29
Ap	0.00	0.00	0.12	0.96	1.73	1.25	0.45
Di (Ca)	7.09	8.92	10.81	12.21	3.32	3.58	3.83
Di (Mg)	3.79	5.09	6.27	7.67	1.82	2.09	2.22
Di (Fe)	3.07	3.45	4.04	3.79	1.38	1.32	1.43
Opx (Mg)	14.24	16.35	14.13	9.29	7.14	4.12	10.13
Opx (Fe)	11.54	11.09	9.10	4.60	5.42	2.61	6.55
Ol (Mg)	0.00	0.00	0.00	2.08	4.12	8.20	1.57
Ol (Fe)	0.00	0.00	0.00	1.13	3.45	5.73	1.12

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Table A5.1

WHOLE-ROCK ANALYSES							
Sample	8202.118	8404.07	8404.06	8404.09	8404.05	8404.04	8404.03
Traverse	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Along Pos.	330.00	330.00	330.00	330.00	330.00	330.00	330.00
Across Pos.	~40 CO	-29.23	-6.73	4.28	21.28	31.29	38.78
Thickness	186.55	186.55	186.55	186.55	186.55	186.55	186.55
Descript.	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE
SiO ₂	49.23	54.19	49.95	48.22	49.23	49.50	49.00
TiO ₂	2.94	1.57	2.90	3.13	2.87	2.89	3.01
Al ₂ O ₃	13.85	19.24	15.94	15.34	16.15	15.91	15.71
Fe ₂ O ₃ T	14.80	7.33	12.68	14.03	12.66	12.91	13.67
FeO	--	4.34	8.80	9.03	8.64	8.75	6.90
FeO(calc)	10.51	5.20	9.00	9.96	8.99	9.17	9.71
MgO	2.87	1.30	2.90	3.15	2.68	2.71	2.96
CaO	7.39	6.95	8.10	8.67	8.23	8.30	8.52
Na ₂ O	4.34	5.23	4.31	4.01	4.16	4.13	4.04
K ₂ O	2.18	2.47	1.91	1.68	1.85	1.89	1.76
P ₂ O ₅	1.41	0.79	1.50	1.68	1.59	1.49	1.63
MnO	0.22	0.11	0.18	0.20	0.18	0.18	0.19
S	0.04	0.01	0.03	0.02	0.03	0.03	0.02
LOI	--	--	--	--	--	--	--
Total	98.10	98.71	99.42	99.12	98.67	98.97	99.74
Zr	197.00	213.00	201.00	182.00	189.00	190.00	162.00
Y	48.00	37.00	41.00	40.00	38.00	42.00	35.00
Nb	33.00	24.00	26.00	23.00	21.00	24.00	24.00
Zn	128.00	85.00	121.00	114.00	118.00	126.00	118.00
Ba	1608.00	1857.00	1539.00	1440.00	1484.00	1490.00	1555.00
Rb	33.00	28.00	26.00	23.00	30.00	32.00	28.00
Sr	655.00	884.00	754.00	774.00	770.00	782.00	779.00
V	146.00	43.00	156.00	253.00	145.00	170.00	261.00
Ni	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr	--	19.99	8.44	3.39	0.00	0.00	1.64
Co	--	--	--	--	--	--	--
Ta	--	--	--	--	--	--	--
Sc	--	--	--	--	--	--	--
Hf	--	--	--	--	--	--	--
U	--	--	--	--	--	--	--
Th	--	--	--	--	--	--	--
La	--	--	--	--	--	--	--
Ce	--	--	--	--	--	--	--
Nd	--	--	--	--	--	--	--
Sm	--	--	--	--	--	--	--
Eu	--	--	--	--	--	--	--
Eu/En*	--	--	--	--	--	--	--
Tb	--	--	--	--	--	--	--
Yb	--	--	--	--	--	--	--
Lu	--	--	--	--	--	--	--
Qtz	0.00	0.00	0.00	0.00	0.00	0.00	1.90
Or	13.14	14.79	11.35	10.02	11.08	11.29	10.43
Ab	37.44	44.84	36.69	34.24	35.68	35.32	34.28
An	12.11	22.01	18.62	19.06	20.21	19.50	19.59
Ne	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Di	13.40	6.38	9.98	11.01	8.91	10.27	9.77
Opx	2.14	2.71	5.62	6.79	7.47	7.45	5.79
Ol	8.14	0.70	4.46	3.11	2.89	2.47	0.00
Mag	4.62	3.68	4.23	5.84	4.49	4.67	8.73
Ilm	5.69	3.02	5.54	6.00	5.53	5.55	5.73
Ap	3.40	1.89	3.57	4.01	3.82	3.57	3.87
Di (Ca)	6.64	3.21	4.99	5.54	4.45	5.13	5.06
Di (Mg)	2.49	1.52	2.18	2.63	1.91	2.20	3.32
Di (Fe)	4.27	1.65	2.81	2.84	2.55	2.93	1.39
Opx (Mg)	0.79	1.30	2.46	3.26	3.19	3.19	4.08
Opx (Fe)	1.35	1.41	3.17	3.53	4.28	4.26	1.71
Ol (Mg)	2.81	0.32	1.84	1.42	1.17	1.00	0.00
Ol (Fe)	5.32	0.38	2.62	1.69	1.72	1.47	0.00

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Table A5.1

WHOLE-ROCK ANALYSES							
Sample#	8404.14	8404.13	8404.12	8404.11	8202.10	8404.10	8404.08
Traverse#	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Along.Pos.	330.00	330.00	330.00	330.00	330.00	330.00	330.00
Across.Pos.	-93.08	-92.63	-91.23	-89.58	-82.58	-59.83	-42.73
Thickness	186.55	186.55	186.55	186.55	186.55	186.55	186.55
Descript.	CHIL.MAR	CHIL.MAR	DYKE	DYKE	DYKE	DYKE	DYKE
SiO ₂	44.84	45.98	46.00	45.28	45.72	44.46	42.06
TiO ₂	2.91	3.53	3.15	3.87	4.38	4.98	4.97
Al ₂ O ₃	16.56	17.46	17.69	16.76	18.54	15.90	11.80
Fe ₂ O ₃ T	14.65	13.92	13.80	14.75	13.38	14.90	19.01
FeO	--	9.16	9.80	10.70	--	10.18	13.25
FeO(calc)	10.40	9.88	9.80	10.47	9.50	10.58	13.50
MgO	7.80	5.27	6.14	5.63	4.67	4.73	5.11
CaO	8.47	9.24	9.16	7.05	8.93	10.69	10.41
Na ₂ O	2.77	3.36	3.21	3.37	3.65	3.10	2.68
K ₂ O	0.61	0.84	0.94	0.97	0.89	0.87	1.21
P ₂ O ₅	0.66	0.90	0.76	0.85	0.57	1.17	3.04
MnO	0.18	0.18	0.17	0.19	0.16	0.19	0.25
S	0.06	0.02	0.03	0.01	0.01	0.01	0.04
LOI	--	--	--	--	0.23	--	--
Total	98.35	99.68	99.96	99.54	100.07	99.87	99.11
Zr	100.00	114.00	115.00	114.00	96.00	106.00	135.00
Y	23.00	25.00	24.00	26.00	18.00	27.00	43.00
Nb	12.00	19.00	14.00	18.00	14.00	18.00	22.00
Zn	102.00	99.00	101.00	114.00	85.00	108.00	135.00
Ba	737.00	742.00	885.00	919.00	792.00	765.00	1052.00
Rb	5.00	9.00	5.00	6.00	10.00	7.00	15.00
Sr	769.00	869.00	887.00	848.00	985.00	790.00	603.00
V	216.00	234.00	192.00	359.00	304.00	395.00	359.00
Co	83.00	23.00	43.00	36.00	21.00	8.00	0.00
Cr	77.84	56.16	55.08	39.49	--	37.13	10.49
Co	--	--	--	--	41.70	--	--
Ta	--	--	--	--	1.18	--	--
Sc	--	--	--	--	19.80	--	--
Hf	--	--	--	--	2.09	--	--
U	--	--	--	--	--	--	--
Th	--	--	--	--	1.05	--	--
La	--	--	--	--	20.10	--	--
Ce	--	--	--	--	43.80	--	--
Nd	--	--	--	--	23.50	--	--
Sm	--	--	--	--	4.61	--	--
Eu	--	--	--	--	2.05	--	--
Eu/Eu*	--	--	--	--	1.55	--	--
Tb	--	--	--	--	0.52	--	--
Yb	--	--	--	--	1.64	--	--
Lu	--	--	--	--	0.25	--	--
Qtz	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Or	3.66	4.98	5.56	5.76	5.27	5.15	7.22
Ab	23.84	28.52	27.18	27.48	29.15	26.26	22.89
An	31.49	30.18	31.11	27.88	31.63	26.94	16.75
Ne	0.00	0.00	0.00	0.63	0.97	0.00	0.00
Di	5.61	8.08	7.69	9.57	7.38	15.13	12.71
Opx	8.50	4.53	0.92	0.00	0.00	0.64	11.38
Ol	15.16	9.44	15.58	15.15	11.85	8.49	6.15
Mag	4.56	5.44	4.22	4.16	4.10	5.21	6.27
Ilm	5.62	6.73	5.99	7.38	8.33	9.47	9.53
Ap	1.59	2.14	1.80	2.02	1.35	2.77	7.27
Di (Ca)	2.87	4.14	3.93	4.87	3.77	7.73	6.41
Di (Mg)	1.69	2.42	2.21	2.61	2.12	4.43	3.11
Di (Fe)	1.05	1.52	1.55	2.10	1.49	2.96	3.19
Opx (Mg)	5.24	2.78	0.54	0.00	0.00	0.38	5.62
Opx (Fe)	3.26	1.75	0.38	0.00	0.00	0.26	5.76
Ol (Mg)	9.00	5.58	8.79	8.04	6.68	4.89	2.89
Ol (Fe)	6.16	3.86	6.79	7.11	5.17	3.60	3.26

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Table A5.1

WHOLE-ROCK ANALYSES

Sample#	8404.02	8404.01	8201.04	8201.03	8201.02	8201.01	8206.04
Traverse#	10.00	10.00	11.00	11.00	11.00	11.00	12.00
Along.Pos.	330.00	330.00	337.00	337.00	337.00	337.00	416.00
Across.Pos.	46.28	54.28	-15.65	32.75	53.35	75.15	-85.90
Thickness	186.55	136.55	160.50	160.50	160.50	160.50	185.00
Descript.	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE
SiO ₂	48.80	48.45	47.37	46.57	44.79	45.93	45.41
TiO ₂	2.93	3.01	3.48	3.66	4.50	3.62	3.68
Al ₂ O ₃	15.82	15.53	13.11	11.44	17.98	19.12	17.84
Fe ₂ O ₃ T	13.30	13.62	17.22	18.36	14.11	12.87	13.41
FeO	8.90	9.17	--	--	--	--	--
FeO(calc)	9.44	9.67	12.23	13.04	10.02	9.14	9.52
MgO	2.90	2.97	3.66	3.79	5.08	5.44	4.73
CaO	8.37	8.49	8.31	8.35	8.55	9.13	9.55
Na ₂ O	4.11	3.78	3.63	3.06	3.63	3.30	3.40
K ₂ O	1.81	1.81	1.80	1.71	0.86	0.78	0.98
P ₂ O ₅	1.55	1.64	1.62	1.94	0.57	0.50	0.84
MnO	0.19	0.19	0.25	0.27	0.17	0.15	0.17
S	0.02	0.05	0.05	0.05	0.01	0.00	0.03
LOI	--	--	1.08	1.29	0.43	0.28	0.25
Total	98.81	98.52	100.22	99.04	99.57	100.10	99.23
Zr	194.00	158.00	174.00	63.00	95.00	83.00	105.00
Y	41.00	39.00	45.00	43.00	20.00	18.00	21.00
Nb	23.00	25.00	26.00	26.00	18.00	12.00	17.00
Zn	118.00	122.00	151.00	180.00	110.00	66.00	63.00
Ba	1486.00	1496.00	1323.00	1725.00	785.00	668.00	803.00
Rb	27.00	29.00	29.00	32.00	6.00	9.00	8.00
Sr	766.00	760.00	663.00	567.00	933.00	1030.00	941.00
V	155.00	154.00	107.00	120.00	421.00	263.00	273.00
Ni	0.00	0.00	0.00	0.00	15.00	45.00	22.00
Cr	2.53	0.00	--	--	--	--	--
Co	--	--	34.00	34.10	45.90	43.60	40.70
Ta	--	--	2.09	2.03	1.29	1.06	1.33
Sc	--	--	31.91	32.04	18.99	16.51	23.93
Hf	--	--	4.53	1.71	2.12	1.47	2.45
U	--	--	--	--	--	0.38	--
Th	--	--	2.80	1.56	0.91	0.70	1.36
La	--	--	45.30	44.00	18.00	15.60	22.60
Ce	--	--	104.40	98.00	40.40	33.90	52.90
Nd	--	--	61.00	60.30	20.60	18.60	30.10
Sm	--	--	11.99	12.29	4.44	3.91	5.89
Eu	--	--	4.35	4.14	2.29	1.84	2.38
Eu/Eu*	--	--	1.24	1.18	1.79	1.60	1.40
Tb	--	--	1.43	1.35	0.51	0.47	0.68
Yb	--	--	3.97	3.26	1.52	1.24	1.78
Lu	--	--	0.59	0.51	0.25	0.20	0.30
Qtz	0.00	0.00	0.00	0.78	0.00	0.00	0.00
Or	10.83	10.86	10.73	10.34	5.12	4.62	5.85
Ab	35.20	32.48	30.99	26.50	28.32	27.97	27.64
An	19.61	20.38	14.29	12.72	30.49	35.12	30.85
Ne	0.00	0.00	0.00	0.00	1.44	0.00	0.78
Di	10.15	9.62	13.98	14.06	6.99	5.70	9.44
Opx	5.78	11.13	7.71	18.14	0.00	1.05	0.00
Ol	4.16	0.82	6.52	0.00	13.32	13.55	12.27
Mag	5.00	5.05	5.32	5.75	4.35	3.94	4.15
Ilm	5.63	5.80	6.67	7.11	8.62	6.89	7.06
Ap	3.72	3.94	3.87	4.70	1.36	1.18	2.01
Di (Ca)	5.09	4.81	6.95	6.98	3.57	2.92	4.80
Di (Mg)	2.25	2.12	2.75	2.71	2.01	1.69	2.58
Di (Fe)	2.82	2.69	4.28	4.37	1.40	1.10	2.06
Opx (Mg)	2.56	4.91	3.02	6.95	0.00	0.63	0.00
Opx (Fe)	3.21	6.23	4.69	11.19	0.00	0.41	0.00
Ol (Mg)	1.75	0.34	2.40	0.00	7.53	7.88	6.53
Ol (Fe)	2.41	0.48	4.12	0.00	5.79	5.67	5.74

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Table A5.1

WHOLE-ROCK ANALYSES							
Sample#	8206.01	8206.03	8206.02	8420.01	8420.05	8420.02	8420.03
Traversed	12.00	12.00	12.00	13.00	13.00	13.00	13.00
Along.Pos.	416.00	416.00	416.00	420.00	420.00	420.00	420.00
Across.Pos.	-81.90	-60.50	-55.35	-104.70	-92.00	-91.00	-89.85
Thickness	135.00	185.00	185.00	185.00	185.00	185.00	185.00
Descript.	DYKE	DYKE	DYKE	SAT. DYKE	DYKE	DYKE	DYKE
SiO ₂	47.33	44.99	43.41	45.54	46.30	45.92	45.26
TiO ₂	3.39	3.87	4.15	3.52	3.20	3.44	3.55
Al ₂ O ₃	18.37	16.55	15.63	16.63	17.31	16.96	16.64
Fe ₂ O ₃ T	12.15	14.17	15.45	14.68	13.44	14.30	14.72
FeO	--	--	--	9.55	9.46	10.60	10.96
FeO(calc)	8.63	10.06	10.97	10.42	9.54	10.15	10.45
MgO	3.20	3.93	4.40	6.38	5.65	6.04	6.48
CaO	9.51	10.70	10.68	8.81	8.95	8.98	8.86
Na ₂ O	4.38	3.38	3.34	3.26	3.49	3.24	3.14
K ₂ O	1.21	1.10	0.89	0.94	1.08	1.09	1.03
P ₂ O ₅	0.97	1.94	2.12	0.87	0.69	0.85	0.78
MnO	0.16	0.18	0.19	0.18	0.17	0.18	0.19
S	0.03	0.01	0.03	0.05	0.04	0.04	0.05
LOI	0.75	0.59	0.27	--	--	--	--
Total	100.49	100.29	99.34	99.80	99.27	99.86	99.48
Zr	130.00	115.00	90.00	118.00	111.00	112.00	111.00
Y	29.00	32.00	29.00	26.00	25.00	27.00	24.00
Nb	21.00	20.00	14.00	13.00	17.00	17.00	15.00
Zn	104.00	102.00	149.00	110.00	101.00	101.00	101.00
Ba	1021.00	946.00	784.00	936.00	904.00	909.00	911.00
Rb	15.00	11.00	9.00	9.00	11.00	12.00	9.00
Sr	970.00	920.00	869.00	817.00	886.00	875.00	850.00
V	204.00	342.00	365.00	225.00	226.00	250.00	216.00
Ni	0.00	10.00	27.00	53.00	42.00	44.00	53.00
Cr	--	--	--	53.00	45.91	44.67	52.84
Co	29.90	34.70	42.00	--	--	--	--
Ta	1.49	1.75	1.31	--	--	--	--
Sc	22.40	28.45	30.50	--	--	--	--
Hf	2.72	2.78	1.97	--	--	--	--
U	0.71	--	0.29	--	--	--	--
Th	1.43	1.20	0.98	--	--	--	--
La	25.40	30.60	28.40	--	--	--	--
Ce	59.20	72.60	69.60	--	--	--	--
Nd	35.70	45.20	42.10	--	--	--	--
Sm	6.98	9.22	9.50	--	--	--	--
Eu	2.89	3.80	3.48	--	--	--	--
Eu/Eu*	1.44	1.42	1.31	--	--	--	--
Tb	0.79	1.08	1.00	--	--	--	--
Yb	1.99	2.37	2.27	--	--	--	--
Lu	0.29	0.38	0.29	--	--	--	--
Qtz	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Or	7.17	6.52	5.31	5.57	6.43	6.45	6.12
Ab	30.13	28.56	27.26	27.65	28.42	27.35	26.13
An	26.97	26.82	25.27	28.04	28.60	28.57	28.43
Ne	3.81	0.07	0.69	0.00	0.72	0.06	0.32
Di	11.60	11.36	11.79	8.19	9.50	8.63	8.74
Opx	0.00	0.00	0.00	3.31	0.00	0.00	0.00
Ol	7.88	10.44	11.99	12.61	14.31	16.77	17.96
Mag	3.73	4.35	4.77	5.91	4.28	3.66	3.70
Ilm	6.46	7.37	7.96	6.70	6.12	6.55	6.78
Ap	2.30	4.61	5.07	2.07	1.65	2.02	1.86
Di (Ca)	5.84	5.73	5.95	4.21	4.85	4.39	4.45
Di (Mg)	2.80	2.79	2.92	2.57	2.72	2.36	2.42
Di (Fe)	2.96	2.84	2.92	1.41	1.93	1.89	1.88
Opx (Mg)	0.00	0.00	0.00	2.14	0.00	0.00	0.00
Opx (Fe)	0.00	0.00	0.00	1.17	0.00	0.00	0.00
Ol (Mg)	3.64	4.92	5.71	7.86	8.03	8.91	9.68
Ol (Fe)	4.24	5.52	6.28	4.75	6.28	7.86	8.28

(Continued on next page)

Table A5.1

WHOLE-ROCK ANALYSES							
Sample#	8420.04	8418.08	8418.07	8207.13	8207.10	8418.10	8419.13A
Traverse#	13.00	14.00	14.00	14.00	14.00	14.00	14.00
Along.Pos.	420.00	427.00	427.00	427.00	427.00	427.00	427.00
Across.Pos.	-67.35	-153.30	-153.00	-152.00	-152.00	-151.80	-109.50
Thickness	185.00	220.00	220.00	220.00	220.00	220.00	220.00
Descript.	DYKE	SAT. DYKE	SAT. DYKE	SAT. DYKE	SAT. DYKE	SAT. DYKE	TONTAM.
SiO ₂	45.44	44.91	45.45	45.17	45.13	45.27	55.37
TiO ₂	3.45	3.36	3.41	3.33	3.37	3.41	1.60
Al ₂ O ₃	16.97	16.57	16.68	16.68	16.56	16.74	15.93
Fe ₂ O ₃ T	14.54	14.08	14.39	14.04	14.35	14.09	12.62
FeO	11.19	9.93	9.77	--	--	9.54	5.63
FeO(calc)	10.32	10.00	10.22	9.97	10.19	10.00	8.96
MgO	6.50	6.25	6.19	6.23	6.25	6.19	3.88
CaO	8.35	8.43	8.65	8.40	8.41	8.49	5.52
Na ₂ O	3.23	2.90	3.02	3.06	3.16	3.04	4.15
K ₂ O	0.97	1.32	0.98	1.03	1.10	0.98	0.59
P ₂ O ₅	0.73	0.80	0.82	0.77	0.78	0.82	0.14
MnO	0.18	0.13	0.20	0.19	0.18	0.18	0.12
S	0.02	0.02	0.02	0.03	0.02	0.02	0.02
LOI	--	--	--	1.80	2.10	--	--
Total	99.63	97.76	98.72	99.62	100.28	98.17	99.31
Zr	110.00	103.00	109.00	104.00	106.00	109.00	122.00
Y	24.00	23.00	27.00	25.00	25.00	26.00	10.00
Nb	13.00	19.00	17.00	18.00	16.00	17.00	6.00
Zn	96.00	99.00	100.00	118.00	141.00	99.00	124.00
Ba	962.00	939.00	677.00	580.00	586.00	551.00	508.00
Rb	4.00	38.00	23.00	25.00	30.00	29.00	7.00
Sr	861.00	674.00	766.00	777.00	728.00	742.00	489.00
V	215.00	323.00	310.00	254.00	275.00	216.00	--
Ni	53.00	46.00	45.00	52.00	58.00	45.00	43.00
Cr	59.93	41.85	44.07	--	--	42.84	--
Co	--	--	--	48.60	48.40	--	--
Ta	--	--	--	1.32	1.42	--	--
Sc	--	--	--	22.54	22.09	--	--
Hf	--	--	--	2.37	2.26	--	--
U	--	--	--	--	--	--	--
Th	--	--	--	1.11	--	--	--
La	--	--	--	24.50	22.60	--	--
Ce	--	--	--	55.00	49.60	--	--
Nd	--	--	--	26.60	26.80	--	--
Sm	--	--	--	5.91	5.95	--	--
Eu	--	--	--	2.53	2.40	--	--
Eu/Eu*	--	--	--	1.47	1.41	--	--
Tb	--	--	--	0.70	0.66	--	--
Yb	--	--	--	1.81	1.62	--	--
Lu	--	--	--	0.29	0.27	--	--
Qtz	0.00	0.00	0.00	0.00	0.00	0.00	11.35
Or	5.75	7.98	5.86	6.22	6.62	5.90	3.51
Ab	25.75	25.10	25.88	26.48	27.24	26.21	35.36
An	29.05	28.95	29.45	29.38	28.27	29.69	23.26
Ne	0.91	0.00	0.00	0.00	0.00	0.00	0.00
Di	8.42	7.14	7.02	6.61	7.40	6.33	2.72
Opx	0.00	3.60	7.44	5.19	1.96	7.64	11.12
Ol	18.77	14.29	10.67	13.43	15.67	10.56	0.00
Mag	3.06	4.52	5.19	4.39	4.47	5.15	9.29
Ilm	5.58	6.53	6.56	6.47	6.52	6.60	3.06
Ap	1.73	1.94	1.97	1.86	1.88	1.98	0.33
Di (Ca)	4.28	3.65	3.59	3.38	3.78	3.25	1.42
Di (Mg)	2.26	2.08	2.10	1.91	2.12	1.92	1.01
Di (Fe)	1.88	1.41	1.33	1.32	1.50	1.16	0.28
Opx (Mg)	0.00	2.15	4.56	3.07	1.15	4.75	8.72
Opx (Fe)	0.00	1.45	2.89	2.12	0.81	2.88	2.40
Ol (Mg)	9.80	8.20	6.28	7.62	8.82	6.33	0.00
Ol (Fe)	8.97	6.10	4.39	5.80	6.85	4.23	0.00

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Table A5.1

WHOLE-ROCK ANALYSES							
Sample#	8207.09	8418.12	8418.04	8207.08	8418.03	8418.02	8418.15
Traverse#	14.00	14.00	14.00	14.00	14.00	14.00	14.00
Along.Pos.	427.00	427.00	427.00	427.00	427.00	427.00	427.00
Across.Pos.	-108.50	-107.25	-95.75	-93.50	-78.65	-63.00	-52.50
Thickness	220.00	220.00	220.00	220.00	220.00	220.00	220.00
Descript.	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE
SiO ₂	45.57	46.03	46.22	45.89	46.63	46.28	46.78
TiO ₂	0.32	0.26	0.93	0.75	0.31	0.34	0.29
Al ₂ O ₃	17.80	19.39	18.45	17.41	17.99	14.99	15.79
Fe ₂ O ₃ T	13.97	12.67	13.27	14.16	13.23	15.84	14.94
FeO	--	9.56	9.45	--	9.00	9.90	10.38
FeO(calc)	9.92	9.00	9.42	10.05	9.39	11.25	10.61
MgO	7.04	7.86	4.01	4.90	3.21	2.86	3.10
CaO	5.71	8.80	9.15	9.20	9.42	8.95	9.95
Na ₂ O	1.13	3.13	3.58	3.46	3.91	3.85	3.82
K ₂ O	0.65	0.57	1.23	1.11	1.29	1.56	1.73
P ₂ O ₅	0.53	0.26	0.67	0.74	1.52	1.67	1.78
MnO	0.17	0.15	0.16	0.18	0.17	0.21	0.21
S	0.04	0.01	0.01	0.01	0.05	0.07	0.06
LOI	0.87	--	--	0.43	--	--	--
Total	100.70	100.07	99.63	100.02	99.73	98.52	99.20
Zr	80.00	64.00	110.00	109.00	132.00	172.00	198.00
Y	17.00	15.00	23.00	23.00	30.00	40.00	43.00
Nb	12.00	5.00	18.00	18.00	21.00	27.00	28.00
Zn	105.00	33.00	143.00	91.00	134.00	169.00	136.00
Ba	570.00	560.00	858.00	895.00	1055.00	1389.00	1511.00
Rb	7.00	1.00	16.00	11.00	18.00	22.00	21.00
Sr	907.00	1015.00	940.00	921.00	928.00	759.00	786.00
Y	286.00	204.00	--	294.00	--	--	139.00
Ni	64.00	86.00	21.00	27.00	0.00	0.00	0.00
Cr	--	202.96	--	--	--	--	0.00
Co	55.30	--	--	40.50	--	--	--
Ta	0.99	--	--	1.48	--	--	--
Sc	18.50	--	--	23.64	--	--	--
Hf	1.51	--	--	2.41	--	--	--
U	--	--	--	0.32	--	--	--
Th	0.72	--	--	1.24	--	--	--
La	17.20	--	--	23.10	--	--	--
Ce	38.70	--	--	52.10	--	--	--
Nd	19.40	--	--	29.00	--	--	--
Sm	4.31	--	--	6.09	--	--	--
Eu	2.04	--	--	2.54	--	--	--
Eu/Eu*	1.62	--	--	1.44	--	--	--
Tb	0.51	--	--	0.70	--	--	--
Yb	1.29	--	--	1.88	--	--	--
Lu	0.21	--	--	0.29	--	--	--
Qtz	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Or	3.85	3.36	7.29	6.58	7.65	9.36	10.30
Ab	26.54	25.05	28.40	27.89	32.43	33.08	32.57
An	32.67	37.16	30.76	28.82	27.82	19.32	20.99
Ne	0.00	0.77	1.09	0.81	0.41	0.00	0.00
Di	5.83	3.90	8.59	10.01	7.56	12.27	10.09
Opx	3.01	0.00	0.00	0.00	0.00	3.20	0.82
Ol	16.27	21.90	10.79	12.66	9.60	5.26	9.80
Mag	4.28	2.96	4.03	4.35	4.69	7.12	4.97
Ilm	6.32	4.29	7.49	7.15	6.31	6.44	6.30
Ap	1.26	0.61	1.59	1.76	3.61	4.02	4.25
Di (Ca)	2.99	2.00	4.35	5.08	3.81	6.14	5.03
Di (Mg)	1.77	1.16	2.24	2.67	1.80	2.70	2.07
Di (Fe)	1.07	0.74	1.99	2.26	1.96	3.43	3.00
Opx (Mg)	1.38	0.00	0.00	0.00	0.00	1.41	0.33
Opx (Fe)	1.14	0.00	0.00	0.00	0.00	1.79	0.49
Ol (Mg)	9.76	12.89	5.45	6.54	4.36	2.19	3.77
Ol (Fe)	6.51	9.01	5.34	6.12	5.24	3.07	6.03

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Table A5.1

WHOLE-ROCK ANALYSES							
Sample#	8207.15	8418.16	8207.07	8418.01	8418.17	8418.18	8418.11
Traverse#	14.00	14.00	14.00	14.00	14.00	14.00	14.00
Along.Pos.	427.00	427.00	427.00	427.00	427.00	427.00	427.00
Across.Pos.	-25.50	-21.50	-3.50	1.50	6.00	15.50	25.00
Thickness	220.00	220.00	220.00	220.00	220.00	220.00	220.00
Descript.	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE
SiO ₂	49.52	50.50	52.84	53.71	51.68	48.89	55.97
TiO ₂	2.46	2.39	2.05	2.06	1.96	2.61	0.96
Al ₂ O ₃	17.53	17.75	18.05	18.38	18.70	17.80	20.86
Fe ₂ O ₃ T	11.65	10.60	9.39	8.77	10.21	12.07	4.32
FeO	--	7.21	--	5.87	6.65	8.43	2.73
FeO(calc)	6.27	7.53	6.67	6.23	7.25	8.57	3.07
MgO	2.18	2.29	1.60	1.54	1.82	2.26	0.40
CaO	7.99	7.69	7.30	6.94	8.00	8.69	5.80
Na ₂ O	4.36	4.32	4.60	4.84	4.53	4.11	5.94
K ₂ O	2.09	2.06	2.07	2.30	2.01	1.72	2.47
P ₂ O ₅	1.16	1.20	0.66	0.71	0.94	1.22	0.55
MnO	0.17	0.15	0.14	0.14	0.15	0.16	0.07
S	0.06	0.02	0.02	0.01	0.01	0.06	0.00
LOI	1.36	--	1.70	--	--	--	--
Total	99.61	98.17	99.68	98.75	99.27	98.65	96.94
Zr	214.00	215.00	182.00	211.00	165.00	155.00	283.00
Y	39.00	39.00	32.00	34.00	33.00	33.00	26.00
Nb	27.00	28.00	25.00	28.00	23.00	27.00	26.00
Zn	104.00	100.00	101.00	99.00	106.00	115.00	116.00
Ba	1520.00	1553.00	1738.00	1521.00	1574.00	1164.00	1388.00
Rb	30.00	36.00	31.00	48.00	34.00	28.00	25.00
Sr	371.00	821.00	851.00	750.00	893.00	865.00	875.00
V	104.00	122.00	133.00	88.00	115.00	--	--
Ni	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr	--	6.61	--	6.79	14.27	--	--
Co	21.10	--	14.80	--	--	--	--
Ta	2.35	--	2.22	--	--	--	--
Sc	18.53	--	18.13	--	--	--	--
Hf	4.76	--	4.17	--	--	--	--
U	0.90	--	0.73	--	--	--	--
Th	2.94	--	2.79	--	--	--	--
La	44.70	--	35.00	--	--	--	--
Ce	99.50	--	76.90	--	--	--	--
Nd	55.00	--	39.10	--	--	--	--
Sm	10.45	--	7.98	--	--	--	--
Eu	4.07	--	3.75	--	--	--	--
Eu/Eu*	1.32	--	1.57	--	--	--	--
Tb	1.28	--	1.02	--	--	--	--
Yb	3.72	--	3.05	--	--	--	--
Lu	0.52	--	0.42	--	--	--	--
Qtz	0.00	0.00	0.64	0.73	0.00	0.00	0.00
Or	12.58	12.40	12.49	13.77	11.96	10.31	15.06
Ab	36.72	37.24	39.73	41.47	38.61	35.27	51.84
An	22.50	23.39	22.96	21.91	24.94	25.40	23.69
Ne	0.46	0.00	0.00	0.00	0.00	0.00	0.00
Di	8.56	6.26	8.13	6.93	7.43	8.62	1.96
Opx	0.00	7.05	7.59	6.26	4.60	2.09	1.77
Ol	8.05	2.38	0.00	0.00	2.39	6.44	0.75
Mag	3.63	3.82	2.93	3.30	4.12	3.97	1.92
Ilm	4.76	4.62	3.97	3.96	3.75	5.03	1.68
Ap	2.80	2.89	1.59	1.70	2.24	2.93	1.34
Di (Ca)	4.24	3.13	4.01	3.45	3.70	4.28	0.96
Di (Mg)	1.53	1.36	1.43	1.39	1.48	1.65	0.27
Di (Fe)	2.74	1.77	2.68	2.09	2.26	2.70	0.73
Opx (Mg)	0.00	3.06	2.64	2.50	1.82	0.79	0.48
Opx (Fe)	0.00	3.99	4.95	3.76	2.78	1.30	1.29
Ol (Mg)	2.77	0.98	0.00	0.00	0.89	2.29	0.19
Ol (Fe)	5.29	1.40	0.00	0.00	1.50	4.15	0.56

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Table A5.1

WHOLE-ROCK ANALYSES							
Sample#	8418.19	8418.20	8418.21	8207.06	8418.22	8418.23	8418.24
Traverse#	14.00	14.00	14.00	14.00	14.00	14.00	14.00
Along.Pos.	427.00	427.00	427.00	427.00	427.00	427.00	427.00
Across.Pos.	44.50	60.50	74.50	83.00	91.85	104.25	107.05
Thickness	220.00	220.00	220.00	220.00	220.00	220.00	220.00
Descript.	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE
SiO ₂	48.25	50.36	45.12	44.78	45.64	45.39	45.73
TiO ₂	2.67	2.72	4.54	4.36	4.14	3.33	3.27
Al ₂ O ₃	16.70	17.43	17.93	16.59	17.68	17.17	17.24
Fe ₂ O ₃ T	13.51	11.77	14.43	15.70	14.06	14.49	14.53
FeO	9.07	7.69	9.99	--	10.20	11.05	10.60
FeO(calc)	9.59	8.36	10.25	11.15	9.98	10.29	10.32
MgO	0.27	1.93	4.74	5.24	4.83	6.94	6.55
CaO	8.27	8.30	8.83	8.38	8.90	8.78	8.87
Na ₂ O	4.31	4.41	3.57	3.53	3.70	3.25	3.31
K ₂ O	1.97	2.07	0.99	1.19	1.01	0.89	0.93
P ₂ O ₅	1.20	0.78	0.82	0.88	0.88	0.72	0.74
MnO	0.20	0.17	0.18	0.19	0.18	0.18	0.18
S	0.07	0.03	0.01	0.03	0.01	0.02	0.03
LOI	--	--	--	0.59	--	--	--
Total	98.41	99.11	100.05	100.22	99.89	99.93	100.20
Zr	216.00	246.00	107.00	127.00	123.00	106.00	113.00
Y	42.00	42.00	22.00	26.00	28.00	23.00	25.00
Nb	34.00	38.00	16.00	21.00	15.00	15.00	13.00
Zn	146.00	123.00	96.00	115.00	94.00	99.00	97.00
Ba	1531.00	1907.00	870.00	913.00	977.00	846.00	891.00
Rb	27.00	27.00	13.00	16.00	6.00	10.00	8.00
Sr	907.00	812.00	905.00	866.00	905.00	871.00	872.00
V	--	55.00	298.00	293.00	207.00	233.00	209.00
Ni	0.00	0.00	17.00	23.00	29.00	59.00	52.00
Cr	--	0.00	20.19	--	43.68	41.25	46.49
Co	--	--	--	46.50	--	--	--
Ta	--	--	--	1.77	--	--	--
Sc	--	--	--	21.19	--	--	--
Hf	--	--	--	2.95	--	--	--
U	--	--	--	--	--	--	--
Th	--	--	--	1.42	--	--	--
La	--	--	--	26.00	--	--	--
Ce	--	--	--	58.20	--	--	--
Nd	--	--	--	30.80	--	--	--
Sm	--	--	--	6.55	--	--	--
Eu	--	--	--	2.54	--	--	--
Eu/Eu*	--	--	--	1.33	--	--	--
Tb	--	--	--	0.78	--	--	--
Yb	--	--	--	1.90	--	--	--
Lu	--	--	--	0.33	--	--	--
Qtz	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Or	11.84	12.35	5.85	7.06	5.98	5.26	5.48
Ab	34.34	36.91	28.93	27.59	28.82	25.54	26.66
An	20.75	21.85	29.97	26.01	28.68	29.66	29.39
Ne	1.48	0.40	0.68	1.30	1.37	1.07	0.70
Di	10.96	12.22	6.93	8.19	8.03	7.57	7.96
Opx	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ol	7.59	4.51	12.30	14.67	13.26	19.69	17.91
Mag	5.06	4.72	4.82	4.82	3.96	3.21	3.98
Ilm	5.16	5.21	8.62	8.31	7.87	6.33	6.20
Ap	2.89	1.86	1.94	2.09	2.09	1.71	1.75
Di (Ca)	5.43	6.08	3.54	4.16	4.08	3.85	4.06
Di (Mg)	2.03	2.44	1.98	2.20	2.16	2.10	2.24
Di (Fe)	3.51	3.70	1.41	1.83	1.79	1.62	1.67
Opx (Mg)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Opx (Fe)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ol (Mg)	2.61	1.69	6.88	7.64	6.92	10.65	9.84
Ol (Fe)	4.98	2.82	5.42	7.02	6.33	9.03	8.06

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Table A5.1

WHOLE-ROCK ANALYSES							
Sample#	8207.02	8207.04	8207.03	8207.05	8207.01	8208.09	8208.08
Traverse#	14.00	14.00	14.00	14.00	14.00	15.00	15.00
Along.Pos.	427.00	427.00	427.00	427.00	427.00	614.00	614.00
Across.Pos.	108.35	108.95	110.00	110.00	110.00	-74.00	-60.00
Thickness	220.00	220.00	220.00	220.00	220.00	148.00	148.00
Descript.	DYKE	CHIL. MAR	CHIL. MAR	CHIL. MAR	CHIL. MAR	CHIL. MAR	DYKE
SiO ₂	45.59	46.08	45.75	45.82	45.59	44.70	45.63
TiO ₂	3.57	3.16	3.42	3.44	3.48	3.46	3.59
Al ₂ O ₃	16.15	17.32	16.73	16.40	16.46	16.22	17.79
Fe ₂ O ₃ T	15.20	13.96	14.40	14.83	14.68	14.63	13.71
FeO	--	--	--	--	--	10.42	9.29
FeO(calc)	10.79	9.93	10.22	10.53	10.42	10.39	9.73
MgO	6.54	6.33	6.23	6.54	6.22	6.28	5.07
CaO	8.75	9.04	8.89	8.86	8.88	8.77	9.13
Na ₂ O	3.22	3.22	3.24	3.28	3.50	3.09	3.55
K ₂ O	0.97	0.90	0.93	0.92	0.95	0.99	0.94
P ₂ O ₅	0.85	0.68	0.81	0.77	0.84	0.83	0.75
MnO	0.19	0.18	0.18	0.19	0.19	0.20	0.17
S	0.01	0.02	0.02	0.04	0.05	0.05	0.04
LOI	0.30	0.44	0.14	0.27	0.15	--	0.56
Total	100.14	100.25	99.60	100.19	99.83	98.06	99.70
Zr	109.00	97.00	103.00	109.00	114.00	113.00	108.00
Y	24.00	19.00	24.00	23.00	24.00	26.00	24.00
Nb	15.00	13.00	15.00	15.00	16.00	14.00	16.00
Zn	87.00	77.00	112.00	115.00	144.00	162.00	98.00
Ba	845.00	797.00	797.00	812.00	861.00	855.00	882.00
Rb	11.00	9.00	9.00	11.00	7.00	6.00	8.00
Sr	834.00	904.00	869.00	852.00	861.00	794.00	906.00
V	272.00	236.00	254.00	267.00	264.00	225.00	285.00
Ni	53.00	49.00	49.00	57.00	67.00	47.00	30.00
Cr	--	--	--	--	--	51.00	--
Co	50.10	49.60	48.60	50.40	50.10	48.70	42.70
Ta	1.42	1.22	1.30	1.44	1.44	1.36	1.29
Sc	23.14	21.41	22.31	22.18	22.76	22.71	20.84
Hf	2.60	2.32	2.27	2.22	2.58	2.12	2.10
U	--	--	--	--	--	--	--
Th	1.18	--	1.05	1.15	1.22	1.38	1.04
La	22.20	19.80	21.70	25.00	24.50	22.40	21.00
Ce	51.00	48.40	51.50	52.00	52.80	52.80	48.50
Nd	30.70	23.40	16.70	31.50	32.10	27.90	23.30
Sm	6.08	5.06	5.60	6.63	6.39	5.82	5.29
Eu	2.45	2.10	2.64	2.42	2.58	2.27	2.16
Eu/Eu*	1.34	1.42	1.71	1.30	1.36	1.31	1.46
Tb	0.78	0.60	0.56	0.70	0.81	0.72	0.56
Yb	1.95	1.77	1.66	2.19	2.18	1.87	1.75
Lu	0.32	0.30	0.27	0.33	0.33	0.29	0.32
Qtz	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Or	5.74	5.33	5.53	5.44	5.63	5.97	5.60
Ab	27.29	27.30	27.57	27.79	27.69	26.67	28.60
An	26.80	30.21	28.52	27.34	26.50	28.02	31.01
Ne	0.00	0.00	0.00	0.00	1.10	0.00	0.00
Di	9.11	8.40	8.60	9.52	10.00	8.88	7.98
Opx	1.77	1.33	2.13	0.68	0.00	1.46	1.47
Ol	15.88	15.55	14.81	16.36	15.99	15.82	11.75
Mag	4.66	4.29	4.43	4.54	4.51	4.51	4.95
Ilm	6.79	6.01	6.53	6.54	6.63	6.70	6.88
Ap	2.02	1.61	1.93	1.82	2.00	2.00	1.79
Di (Ca)	4.65	4.29	4.39	4.86	5.10	4.53	4.97
Di (Mg)	2.60	2.43	2.47	2.74	2.84	2.53	2.32
Di (Fe)	1.86	1.68	1.74	1.92	2.05	1.82	1.59
Opx (Mg)	1.03	0.79	1.25	0.40	0.00	0.85	0.87
Opx (Fe)	0.74	0.55	0.88	0.28	0.00	0.61	0.60
Ol (Mg)	8.39	8.82	8.33	9.23	8.90	8.82	6.70
Ol (Fe)	6.99	6.73	6.48	7.13	7.09	7.00	5.05

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Table A5.1

WHOLE-ROCK ANALYSES							
Sample#	8208.07	8208.06	8208.03	8208.05	8208.02	8208.04	8209.01
Traverse#	15.00	15.00	15.00	15.00	15.00	15.00	16.00
Along.Pos.	614.00	614.00	614.00	614.00	614.00	614.00	702.00
Across.Pos.	-50.35	-30.65	-19.00	-15.35	1.00	13.00	-13.15
Thickness	146.00	148.00	148.00	148.00	148.00	148.00	85.00
Descript.	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE
SiO ₂	45.70	46.26	40.74	46.47	47.61	48.50	45.09
TiO ₂	3.88	3.48	2.25	3.24	2.92	2.72	3.50
Al ₂ O ₃	18.51	18.17	19.42	17.45	18.32	18.96	16.63
Fe ₂ O ₃ T	13.19	12.69	9.93	12.53	11.83	10.98	14.60
FeO	8.90	--	--	--	7.72	--	10.65
FeO(calc)	9.36	9.01	7.05	8.90	8.40	7.80	10.37
MgO	4.28	3.79	2.18	3.40	3.18	2.97	6.08
CaO	9.16	9.35	9.03	9.71	8.60	8.12	8.61
Na ₂ O	3.65	3.61	4.34	3.91	4.15	4.03	3.33
K ₂ O	1.02	1.12	1.39	1.14	1.37	1.60	1.05
P ₂ O ₅	0.78	1.00	1.25	1.21	0.73	0.54	0.81
MnO	0.16	0.17	0.14	0.16	0.16	0.15	0.18
S	0.04	0.05	0.05	0.07	0.05	0.05	0.06
LOI	--	1.20	1.67	1.51	1.44	1.51	1.02
Total	99.38	99.89	99.61	99.81	99.50	99.26	99.77
Zr	117.00	127.00	157.00	131.00	150.00	178.00	112.00
Y	23.00	29.00	32.00	29.00	26.00	29.00	27.00
Nb	15.00	17.00	22.00	17.00	21.00	23.00	17.00
Zn	34.00	94.00	80.00	105.00	97.00	117.00	118.00
Ba	302.00	976.00	1150.00	1051.00	1069.00	1249.00	905.00
Rb	7.00	9.00	15.00	14.00	19.00	20.00	13.00
Sr	928.00	928.00	1032.00	915.00	961.00	905.00	832.00
V	242.00	209.00	107.00	216.00	191.00	159.00	279.00
Ni	15.00	12.00	0.00	0.00	13.00	1.00	47.00
Cr	--	--	--	--	--	--	--
Co	37.20	34.70	21.60	32.40	27.60	27.10	50.40
Ta	1.33	1.62	1.66	1.64	1.87	2.07	1.44
Sc	20.01	20.84	12.57	23.71	19.60	16.13	22.62
Hf	2.59	2.87	3.51	3.02	3.50	3.69	2.65
U	0.34	--	0.42	0.39	--	0.49	0.23
Th	1.17	1.48	1.95	1.59	1.76	2.42	1.20
La	21.60	27.90	35.90	31.10	31.60	31.30	25.00
Ce	49.90	65.90	78.30	67.00	66.80	70.20	55.10
Nd	26.40	35.40	40.80	37.90	35.80	34.00	26.50
Sm	5.52	7.16	8.61	8.11	7.30	6.78	6.16
Eu	2.40	2.80	3.58	3.40	3.06	2.68	2.49
Eu/Eu*	1.55	1.45	1.42	1.42	1.50	1.37	1.35
Tb	0.58	0.67	1.04	0.98	0.77	0.75	0.80
Yb	1.74	2.22	2.73	2.47	2.45	2.51	1.99
Lu	0.29	0.33	0.41	0.39	0.38	0.37	0.31
Qtz	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Or	6.06	6.71	8.39	6.86	9.26	9.68	6.28
Ab	29.41	30.89	36.93	31.07	33.70	34.52	27.23
An	31.32	30.49	30.04	27.18	27.87	29.60	27.69
Ne	0.91	0.04	0.31	1.41	1.15	0.21	0.72
Di	7.60	8.20	6.19	11.47	8.90	6.66	8.40
Opx	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ol	10.64	10.70	7.71	8.99	7.93	9.33	16.99
Mag	4.81	3.93	3.10	3.90	4.81	3.44	4.06
Him	7.42	6.70	4.36	6.26	5.66	5.29	6.73
Ap	1.86	2.40	3.02	2.92	1.76	1.31	1.94
Di (Ca)	3.88	4.14	3.09	5.77	4.51	3.35	4.27
Di (Mg)	2.18	2.09	1.28	2.74	2.34	1.57	2.32
Di (Fe)	1.54	1.97	1.83	2.95	2.05	1.74	1.81
Opx (Mg)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Opx (Fe)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ol (Mg)	5.99	5.24	2.99	4.12	4.03	4.20	9.13
Ol (Fe)	4.65	5.45	4.71	4.88	3.90	5.13	7.86

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Table A5.1

WHOLE-ROCK ANALYSES					
Sample#	8209.02	8209.03	8209.04	8209.05	8209.06
Traverse#	16.00	16.00	16.00	16.00	16.00
Along.Pos.	702.00	702.00	702.00	702.00	702.00
Across.Pos.	1.00	11.10	17.35	20.75	32.10
Thickness	85.00	85.00	85.00	85.00	85.00
Descript.	DYKE	DYKE	DYKE	DYKE	DYKE
SiO ₂	44.82	46.98	45.03	46.07	47.15
TiO ₂	3.77	3.23	3.71	3.46	2.94
Al ₂ O ₃	16.42	17.87	16.37	17.21	19.76
Fe ₂ O ₃ T	13.94	13.14	15.01	12.99	10.40
FeO	9.67	--	10.46	8.60	--
FeO(calc)	9.90	9.33	10.66	9.22	7.38
MgO	4.38	4.07	4.75	3.84	3.28
CaO	9.94	8.68	8.64	9.38	9.48
Na ₂ O	3.31	3.74	3.42	3.62	3.73
K ₂ O	1.11	1.33	1.23	1.38	1.18
P ₂ O ₅	1.63	0.91	1.23	1.23	0.78
MnO	0.18	0.18	0.20	0.17	0.14
S	0.08	0.04	0.07	0.05	0.05
LOI	1.50	1.27	1.25	--	1.60
Total	100.00	100.40	99.75	98.44	99.67
Zr	125.00	137.00	132.00	143.00	114.00
Y	31.00	32.00	30.00	31.00	27.00
Nb	17.00	19.00	22.00	22.00	15.00
Zn	105.00	112.00	115.00	102.00	89.00
Ra	949.00	1153.00	1024.00	1126.00	974.00
Rb	12.00	16.00	14.00	20.00	11.00
Sr	849.00	921.00	848.00	864.00	1021.00
V	282.00	191.00	243.00	193.00	166.00
Ni	10.00	15.00	15.00	10.00	10.00
Cr	--	21.17	--	--	22.51
Co	38.10	35.90	41.20	32.30	28.30
Ta	1.63	1.63	1.59	1.80	1.35
Sc	25.80	19.08	20.81	24.88	18.98
Hf	2.73	3.03	3.08	3.03	2.31
U	0.17	0.27	0.21	0.44	0.22
Th	1.49	1.49	1.47	1.39	1.24
La	31.06	29.60	30.70	30.70	23.80
Ce	71.80	62.00	68.50	71.10	52.10
Nd	42.30	35.70	41.70	35.90	28.70
Sm	8.82	7.26	7.90	7.81	5.99
Eu	3.37	2.97	3.11	3.01	2.60
Eu/Eu ⁺	1.30	1.37	1.33	1.27	1.61
Tb	1.01	0.92	0.97	1.06	0.56
Yb	2.53	2.42	2.61	2.22	1.81
Lu	0.36	0.36	0.35	0.35	0.30
Qtz	0.00	0.00	0.00	0.00	0.00
Or	6.66	7.93	7.38	8.29	7.11
Ab	28.46	31.51	29.40	30.68	31.40
An	27.09	28.30	26.10	27.07	34.37
Ne	0.00	0.23	0.00	0.24	0.43
Di	10.04	7.57	7.67	9.90	6.93
Opx	2.08	0.00	1.56	0.00	0.00
Ol	9.85	12.08	12.86	9.18	8.97
Mag	4.70	4.06	4.99	5.06	3.24
Ilm	7.27	6.19	7.16	6.68	5.70
Ap	3.92	2.17	2.96	2.96	1.88
Di (Ca)	5.09	3.83	3.88	5.04	3.51
Di (Mg)	2.68	1.90	1.99	2.72	1.82
Di (Fe)	2.27	1.85	1.79	2.15	1.60
Opx (Mg)	1.13	0.00	0.82	0.00	0.00
Opx (Fe)	0.95	0.00	0.74	0.00	0.00
Ol (Mg)	5.10	5.84	6.45	4.91	4.56
Ol (Fe)	4.75	6.24	6.40	4.27	4.40

APPENDIX 6: THEORY AND APPLICATION OF PEARCE RATIOS

A6.1 INTRODUCTION

Pearce ratio diagrams (Pearce, 1978; Russell, 1986; Pearce, 1987; Russell and Nicholls, 1988; Nicholls, 1988) also termed molecular proportion ratio (MPR) diagrams (e.g. Rollinson and Roberts, 1986) were originally developed by Pearce (1968, 1970) to defeat the closure problem which can cause distorted trends on Harker and ternary weight percent diagrams (e.g. Chayes, 1971).

In geochemistry, Pearce ratio diagrams (e.g. Fig. A6.1) are plots of A/Z vs B/Z where A, B and Z are compositional abundances of elements or oxides and Z has a constant absolute abundance (e.g. it is neither added to nor subtracted from the system under the process being studied). On such a diagram the data from a co-genetic suite of samples are distributed along a trend with a slope equal to the bulk A:B ratio of the minerals lost or gained from the system. The proportion of minerals removed (or added) can also, of course, be determined using least-squares mixing calculations as devised, for example, by Bryan et al. (1969) or Wright and Doherty (1970). However, the least-squares mixing approach requires assumption of the identity of the minerals being removed (or added). In contrast, the identity of the participating minerals can, in certain cases, be uniquely determined simply from the slope of the data distribution on Pearce ratio diagrams.

This approach has been applied to fractionation in igneous bodies (e.g. Beswick, 1982; 1983; Kalsbeek and Jepsen, 1984; Pearce

and Birkett, 1974) where an incompatible element has been used for Z. The technique has also been applied in studies of alteration (e.g. Beswick, 1983), in which case, an immobile element is the appropriate choice for Z.

Recently, there has been much discussion in the literature as to whether data trends on Pearce ratio diagrams may suffer from spurious or enhanced correlations (e.g. Rollinson and Roberts, 1986; 1987; Vines, 1987; Pearce, 1987). The following provides a review and amplification of the theoretical foundation of the approach and presents further refinements and applications of the technique.

A6.2 THEORY

Let us consider a series of samples whose chemical analyses describe different states (or stages) of a system. These samples are assumed to be genetically related so that each may be derived, one from another by some process (e.g. fractional crystallization).

In general terms, each sample of such a system will have the following relationship:

$$^*A_i + ^*B_i + \dots + ^*Z_i = ^*T_i \quad (\text{A6.1})$$

where the subscript 'i' (=1, 2, 3, ...) labels the sample and *A_i , *B_i , ..., *Z_i and *T_i denote the absolute abundances of compositional variables (e.g. SiO_2) and have units such as grams, moles, liters, etc. The following relationships must also be true:

$$A_i = ^*A_i / ^*T_i \quad (\text{A6.2a})$$

$$B_i = ^*B_i / ^*T_i \quad (\text{A6.2b})$$

$$Z_i = ^*Z_i / ^*T_i \quad (\text{A6.2c})$$

$$\text{and } A_i + B_i + \dots + Z_i = 1 \text{ (or 100\%)} \quad (\text{A6.2d})$$

The variables, A_i , B_i , ..., Z_i are the fractional or percentages abundances (e.g. wt% SiO_2 or ppm Ni). In making comparisons between different samples (e.g. $i = 1$ and $i = 2$) one approach is to consider ${}^*T_i = 1$ (or 100%). As a consequence equations A6.2a-c reduce to:

$$A_i = {}^*A_i \quad (\text{A6.3a})$$

$$B_i = {}^*B_i \quad (\text{A6.3b})$$

$$Z_i = {}^*Z_i \quad (\text{A6.3c})$$

and also:

$${}^*A_i + {}^*B_i + \dots + {}^*Z_i = A_i + B_i + \dots + Z_i = 1 \text{ (or 100\%)} \quad (\text{A6.3d})$$

This is the approach implied when wt% data (e.g. wt% SiO_2) are compared directly, i.e. subtracted, added (e.g. wt% Na_2O + wt% K_2O), or plotted on a Harker diagram (e.g. wt% MgO vs wt% SiO_2). This approach is valid for cases in which *T_i is a constant for the process being studied.

An alternative approach is to constrain another variable (or a combination of variables) in equation A6.1 to be constant and allow *T_i to be different for each sample. This reflects the reality of many geological processes in which the total mass (or volume, moles, etc.) of a system grows or shrinks due to the process being studied. For instance, consider a co-genetic suite related by fractional crystallization, a process in which crystals are removed as they form and hence, a process for which *T is not constant. Instead, constrain *Z_i to be constant. In other words, select an element, *Z_i , which is

studied. Therefore, it remains constant in abundance and equal to its initial abundance, *Z_0 . In studying fractional crystallization an incompatible element may be used as the constant denominator, *Z (e.g. $^*Z_i = ^*La_i = ^*La_0$, when olivine is on the liquidus in a basaltic liquid). Then:

$$A_i/Z_i = (^*A_i/^*T_i)/(^*Z_i/^*T_i) = ^*A_i/^*Z_i = ^*A_i/^*Z_0 \quad (A6.4a)$$

$$B_i/Z_i = (^*B_i/^*T_i)/(^*Z_i/^*T_i) = ^*B_i/^*Z_i = ^*B_i/^*Z_0 \quad (A6.4b)$$

These terms in equation A6.4a and A6.4b (herein named Pearce ratios) show that a Pearce ratio diagram, which graphs A_i/Z_i vs B_i/Z_i is equivalent to a graph of $^*A_i/^*Z_0$ vs $^*B_i/^*Z_0$ (where *Z_0 is a constant). The correlation coefficient for a plot of A_i/Z_0 vs B_i/Z_0 is identical to that for a plot of *A_i vs *B_i , where *A_i and *B_i are absolute amounts of compositional variables (e.g. elements) A and B. In contrast, the correlation coefficient on a Harker plot of A_i vs B_i is actually that of $^*A_i/^*T_i$ vs. $^*B_i/^*T_i$, and it may be spurious when *T_i is not constant.

The absence of enhanced correlations on Pearce ratio diagrams can also be demonstrated by another approach. The null correlation is the correlation to be expected between $^*A/^*Z$ and $^*B/^*Z$ in the absence of a correlation between *A , *B and *Z , and is calculated as follows (Chayes 1971, p. 14):

$$U^*A \cdot U^*B \cdot \sigma^*Z^2 / ((U^*Z^2 \cdot \sigma^*A^2 + U^*A^2 \cdot \sigma^*Z^2)(U^*Z^2 \cdot \sigma^*B^2 + U^*B^2 \cdot \sigma^*Z^2))^{0.5} \quad (A6.5)$$

where U^*A , U^*B , U^*Z and σ^*A , σ^*B , σ^*Z are the means and standard

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this expression is non-zero, and therefore, enhanced correlation occurs. However, when *Z is constant (and a plot of A/Z vs B/Z is, therefore, by definition a Pearce ratio diagram) then $\sigma_{\bullet Z} = 0$ and the null correlation is also zero for a plot of $^*A/^*Z (=A/Z)$ vs $^*B/^*Z (=B/Z)$.

In equations A6.4a & b, the data is scaled by Z_i . The particular choice of variable Z (e.g. Zr , K_2O , Th , La) used in ratios of the form A_i/Z_i will scale the data by its magnitude. It is, therefore, useful to remove this scaling by normalizing Z_i to a reference sample Z_0 (i.e. Z_i/Z_0) and using this new term to normalize the compositional data as in equations A6.6a & b:

$$A_i(Z_0/Z_i) = ^*A_i/^*T_0 = ^*A_i \cdot Z_0/^*Z_0 \quad (A6.6a)$$

$$B_i(Z_0/Z_i) = ^*B_i/^*T_0 = ^*B_i \cdot Z_0/^*Z_0 \quad (A6.6b)$$

The terms in eqn. A6.6a and A6.6b are herein named normalized Pearce ratios. The choice of the reference sample depends on the type of problem being studied. For example, the reference sample might be the most primitive sample of a suite of samples which are interrelated by fractional crystallization, or, in general, the "parent" from which all other samples are derived.

The absolute abundances, *A_i and *B_i , (in equations A6.6a & b) are expressed as a fraction of the reference sample total, *T_0 . Subtraction of data from different samples transformed as in equations A6.6a & b (normalized Pearce ratios) has a very useful characteristic:

$$A_i(Z_0/Z_i) - A_0(Z_0/Z_0) = (^*A_i - ^*A_0)/^*T_0 \quad (A6.7)$$

Thus, the difference equals the fractional loss (or gain) in

compositional variable, A_i , from a reference sample to produce the abundance in the daughter sample. By contrast, simply subtracting the measured fractional abundances:

$$A_i - A_0 = {}^*A_i/{}^*T_i - {}^*A_0/{}^*T_0 \quad (\text{A6.8})$$

(where, for example, A = wt% SiO_2) has no simple quantitative meaning.

A6.3 CHOICE OF Z

The choice of Z is entirely model dependent. For a co-genetic suite of samples, any element can theoretically be used as element Z , but the resulting trends can most readily be interpreted or understood in terms of a model designed so that for all samples, *Z , is in fact, constant. For instance, in considering a fractionating magma chamber, it is most useful to choose an incompatible element as variable Z , in which case, data slopes give fractional loss from, and cumulate gains to the liquid.

However, it may be possible to redefine the system so that an appropriate choice for Z , is an element with variation linked to fractionation of a single mineral species, e.g. Ni in olivine. In this case, the data slopes would reflect the loss or addition of minerals and liquid from a magma chamber with respect to a constant amount of olivine. This approach may be useful in studying, for instance, filter pressing of liquid from an olivine cumulate.

A6.4 INTERPRETATION OF MINERAL LOSSES AND GAINS

Compositional variables (e.g. SiO_2 , Zr) are additive, linear functions of the abundance of mineral species (Pearce, 1968; Reid et

al., 1973). Therefore, material balance equations can be written which relate the change in absolute compositional abundances (e.g. Δ^*A_i , Δ^*B_j) to the mineral species being lost or gained from the system:

$$\Delta^*A = k \cdot \sum M_{A,m} \cdot P_m \quad (A6.9a)$$

$$\Delta^*B = k \cdot \sum M_{B,m} \cdot P_m \quad (A6.9b)$$

$$\frac{\Delta^*A}{\Delta^*B} = \frac{\sum M_{A,m} \cdot P_m}{\sum M_{B,m} \cdot P_m} \quad (A6.9c)$$

$M_{A,m}$ and $M_{B,m}$ are the concentrations (e.g. moles) of the elements A and B in the mineral 'm' ($m = 1, 2, 3, \dots$). P_m is the proportion of mineral 'm' (e.g. mole fractions) being removed from or added to the system. The proportionality constant, 'k', serves to scale the system; it cancels out when eqns. A6.9a and A6.9b are divided in order to derive eqn A6.9c. Values of P_m are normalized by summation over all minerals:

$$\sum P_m = 1 \quad (A6.10)$$

Dividing both the numerator and denominator of equation A6.9c by the constant *Z_0 and using the results of equation 4 we can show:

$$\frac{\Delta^*A}{\Delta^*B} = \frac{\Delta(^*A/^*Z_0)}{\Delta(^*B/^*Z_0)} = \frac{\Delta(A/Z)}{\Delta(B/Z)} = \frac{\sum M_{A,m} \cdot P_m}{\sum M_{B,m} \cdot P_m} \quad (A6.11)$$

Therefore, the slope on a plot of A/Z vs B/Z equals the ratio $\Delta^*A : \Delta^*B$ which is in turn related to proportions of mineral losses and gains.

As an example, the changes in Si and Al which can be attributed to the fractionation of common minerals in a mafic igneous melt (see

Fig. A6.2) can be represented by equations A6.12a-c. For general utility, this is worked in molar abundances, however, the conversion to volume or mass units is easily accomplished.

$$\triangle^*A = \triangle^*Si = k \cdot [1 \cdot P_{Ol} + 1 \cdot P_{Opx} + 2 \cdot P_{Cpx} + 2 \cdot P_{An} + 3 \cdot P_{Ab} + 3 \cdot P_{Kfs} + 1 \cdot P_{Qtz}] \quad (A6.12a)$$

$$\triangle^*B = \triangle^*Al = k \cdot [2 \cdot P_{An} + 1 \cdot P_{Ab} + 1 \cdot P_{Kfs}] \quad (A6.12b)$$

$$\frac{\triangle^*A}{\triangle^*B} = \frac{\triangle(A/Z)}{\triangle(B/Z)} = \frac{1 \cdot P_{Ol} + 1 \cdot P_{Opx} + 2 \cdot P_{Cpx} + 2 \cdot P_{An} + 3 \cdot P_{Ab} + 3 \cdot P_{Kfs} + 1 \cdot P_{Qtz}}{2 \cdot P_{An} + 1 \cdot P_{Ab} + 1 \cdot P_{Kfs}} \quad (A6.12c)$$

Other examples are:

$$\triangle^*C = \triangle^*Ca = k \cdot [1 \cdot P_{Cpx} + 1 \cdot P_{An} + 5 \cdot P_{Ap}] \quad (A6.13a)$$

$$\triangle^*D = \triangle^*(Mg+Fe^{2+}) = k \cdot [2 \cdot P_{Ol} + 1 \cdot P_{Opx} + 1 \cdot P_{Cpx} + 1 \cdot P_{Ilm} + 3 \cdot P_{Usp50}] \quad (A6.13b)$$

(Mineral abbreviations used throughout this paper are from Kretz, 1983 and Usp50 represents the mid-range composition of the titanomagnetite solid solution series.)

The values for P_m ($m = 1, 2, 3 \dots$) in molecular amounts can be converted to wt% by multiplying each P_m by the molecular weight of each mineral, 'm', and normalizing the resulting mineral weights so that they sum to 100%.

The mineral losses and gains can be depicted graphically (e.g. Fig. A6.2). The slope of each mineral vector is determined by its ratio $\triangle^*A : \triangle^*B$. The length of each mineral vector is related to the change in mineral species proportion, P_m , by the following expression:

$$\text{VECTOR LENGTH}_m = [(\Delta^* A_m)^2 + (\Delta^* B_m)^2]^{0.5} = k \cdot P_m \cdot (M_{A,m}^2 + M_{B,m}^2)^{0.5} \quad (\text{A6.14})$$

A6.5 COMPLEX NUMERATORS

Because of the additive property of compositions (Pearce, 1968), linear combinations of compositional variables can be used as numerators. Judicious choice of such complex numerators can simplify the analysis of data and provide critical tests between alternative hypotheses. Pearce (1968; 1970; 1972) and Dykes, 1979) have suggested the use of numerators such as $\text{MgO} + \text{FeO}$, or $1.5 \cdot \text{CaO} + 0.5 \cdot \text{MgO} + 0.5 \cdot \text{FeO}$, termed the Silica Mafic Equivalent (SME) function.

The procedure is given below for designing complex numerators specifically suited for any system. (This derivation is worked in molar amounts; it can also be done in mass or volume units.) The first step is to devise equations (e.g. equations A6.12 and A6.13) derived from mineral stoichiometry, which sum the contribution from each mineral species to the abundances of particular elements.

Appropriately chosen linear combination of these and similar equations will yield equations such as the following. (This approach is similar to that employed in calculating modal mineral proportions from a chemical analysis, e.g. CIPW norms).

$$\Delta (^{*}\text{Al}/2 + ^{*}\text{Na}/2 - ^{*}\text{K}/2) = k \cdot [1 \cdot \text{P}_{\text{Ab}} + 1 \cdot \text{P}_{\text{An}}] = k \cdot [1 \cdot \text{P}_{\text{Pl}}] \quad (\text{A6.15a})$$

$$\Delta (^{*}\text{Si} - 2 \cdot ^{*}\text{Ca} - 3 \cdot ^{*}\text{K} - 3 \cdot ^{*}\text{Na} + (10/3) \cdot ^{*}\text{P}) = k \cdot [1 \cdot \text{P}_{\text{Opx}} + 1 \cdot \text{P}_{\text{Ol}} + 1 \cdot \text{P}_{\text{Qtz}}] \quad (\text{A6.15b})$$

$$\Delta (^{*}\text{Ca} + ^{*}\text{Na} - (5/3) \cdot ^{*}\text{P}) = k \cdot [1 \cdot \text{P}_{\text{Cpx}} + 1 \cdot \text{P}_{\text{Pl}}] \quad (\text{A6.15c})$$

These equations isolate the variation in the abundance of specific minerals and allow testing of fractionation hypotheses.

Consider a plot of:

$$(\text{Al}/2 + \text{Na}/2 - \text{K}/2)/Z \quad \text{vs} \quad (\text{Ca} + \text{Na} - (5/3) \cdot \text{P})/Z$$

Using the results of equations 11 and 15 the slope is shown to be:

$$\frac{\Delta [(\text{Al}/2 + \text{Na}/2 - \text{K}/2)/Z]}{\Delta [(\text{Ca} + \text{Na} - (5/3) \cdot \text{P})/Z]} = \frac{\Delta (^{*}\text{Al}/2 + ^{*}\text{Na}/2 - ^{*}\text{K}/2)}{\Delta (^{*}\text{Ca} + ^{*}\text{Na} - (5/3) \cdot ^{*}\text{P})} = \frac{1 \cdot \text{P}_{\text{Pl}}}{1 \cdot \text{P}_{\text{Cpx}} + 1 \cdot \text{P}_{\text{Pl}}} \quad (\text{A6.16})$$

The slope is controlled by fractional losses or gains of plagioclase and clinopyroxene only (Fig. A6.3); fractionation of any other mineral species will have no effect on the distribution of data on this particular diagram. The data from the Great Abitibi gabbro dyke (Fig. A6.3) shows that the fractionation of plagioclase dominates over that of clinopyroxene.

CIPW normative wt% abundances may be used as numerator variables. For instance, a plot of $\text{PLAG}(\text{NORM})/Z$ vs $\text{CPX}(\text{NORM})/Z$ can be used to assess the relative degree of plagioclase and clinopyroxene fractionation.

Complex numerator formulas can also be devised utilizing the analyzed compositions of fractionating mineral phases rather than ideal stoichiometry, as in CIPW norms. These can be generated by

inverting the whole rock and mineral chemical analyses into proportions of modal minerals (e.g. Reid et al., 1973; Albarede, and Provost, 1977).

Another useful approach is to plot values of $A_i \cdot Z_0 / Z_i$ (normalized Pearce ratios) vs. geographic position. Data from a representative traverse across the Great Abitibi gabbro dyke is presented (Fig. A6.4). CIPW normative mineral abundances are used as the complex numerator variables. Comparison is made between plots of CIPW mineral abundances and values of $A_i \cdot Z_0 / Z_i$ produced by multiplying CIPW mineral abundances by Ba_0 / Ba_i . (Note that when A and Z are in units of weight percent, then the changes in normalized Pearce ratio abundances will also be in wt%.) In each case, these normalized Pearce ratio plots provide useful genetic information which is unavailable from the plots of the 'raw' CIPW abundances. It is seen that the absolute abundance of clinopyroxene (normative diopside ; Ba_0 / Ba_i) is essentially constant across the dyke while the interior of the dyke has undergone substantial fractional loss of plagioclase (approximately 40 wt%). In other words, nearly half of the original magma was lost through fractional crystallization of plagioclase and clinopyroxene (40 wt% plagioclase and 5 wt% clinopyroxene; percentages are based on original amount of magma). In Fig. A6.4d notice the two large spikes; these indicate excess clinopyroxene (i.e. cumulates) and occur at an internal contact in the dyke.

A6.6 AFFECT OF LIMITED NON-CONSTANCY IN THE CONSTANT ELEMENT

As absolute incompatibility does not exist by virtue of the fact

that minor amounts of material may be trapped in defects or inclusions, and because it may not be possible to find absolutely incompatible elements for all systems of interest, we have examined the error resulting from limited compatibility during fractional crystallization.

The effect of non-incompatibility in the constant denominator element is evaluated as it affects both Pearce ratios and data-slopes on Pearce ratio diagrams for the case of fractional crystallization.

The degree of incompatibility can be monitored using the bulk mineral/melt distribution coefficient, D . In this analysis, *A , A , *B , B , *Z , Z and *T are as defined earlier. The bulk distribution coefficient can be expressed in the form:

$$D = (\sum ^*Z_m / \sum ^*T_m) / (^*Z/^*T)_{\text{melt}} \quad (\text{A6.17})$$

($m = 1, 2, 3, \dots$ labels different mineral species).

For perfect fractional crystallization the following equations apply:

$$\sum ^*Z_m = d^*Z_{\text{melt}} \quad (\text{A6.18a})$$

$$\sum ^*T_m = d^*T_{\text{melt}} \quad (\text{A6.18b})$$

and, therefore:

$$\sum ^*Z_m / \sum ^*T_m = (d^*Z/d^*T)_{\text{melt}} \quad (\text{A6.18c})$$

In other words, the amount lost from a melt by crystallization equals the amount taken up by the crystallizing minerals.

Substituting equation A6.18c into A6.17 (and dropping the 'melt' subscripts) and some rearranging results in

$$D \cdot (d^*T/^*T) = d^*Z/^*Z \quad (\text{A6.19})$$

Integration and rearrangement yields:

$$^*Z = ^*Z_0 \cdot (^*T/^*T_0)^D \quad (\text{A6.20})$$

*T_0 and *Z_0 are the initial values of *T and *Z . The affect on the slope of the data (SLOPE) on Pearce ratio diagrams (plotting A/Z vs B/Z) is assessed as follows:

$$\text{SLOPE} = d(A/Z)/d(B/Z) = d(^*A/^*Z)/d(^*B/^*Z) \quad (\text{A6.21})$$

Substitution of eqn A6.20 into A6.21 yields:

$$\text{SLOPE} = d(^*A/(^*Z_0 \cdot (^*T/^*T_0)^D))/d(^*B/(^*Z_0 \cdot (^*T/^*T_0)^D)) = d(^*A/^*T^D)/d(^*B/^*T^D) \quad (\text{A6.22})$$

Expansion of the derivatives and some rearranging yields:

$$\text{SLOPE} = [d^*A/d^*B] \cdot [1 - (D \cdot ^*A/^*T) \cdot (d^*T/d^*A)] / [1 - (D \cdot ^*B/^*T) \cdot (d^*T/d^*B)] \quad (\text{A6.23})$$

It is assumed that *A , *B , *C ... have been removed or added to the system in a fixed ratio. From this it can be shown that:

$$a \cdot d^*A + d^*Z = d^*T \quad (\text{A6.24})$$

where 'a' is a proportionality constant. Substitution of eqn A6.20 into eqn A6.24, expansion of the derivatives, and some rearrangement yields:

$$d^*T/d^*A = a / ((1 - D \cdot (^*Z_0/^*T_0) \cdot (^*T/^*T_0)^{D-1})) = a / (1 - D \cdot Z_0 \cdot F^{D-1}) \quad (\text{A6.25})$$

where a is a constant and $F = ^*T/^*T_0$ and $Z_0 = ^*Z_0/^*T_0$.

By a similar derivation:

$$d^*T/d^*B = b / (1 - D \cdot Z_0 \cdot F^{D-1}) \quad (\text{A6.26})$$

where b is a constant. Combining eqns A6.25 and A6.26 yields:

$$d^*A/d^*B = b/a \quad (\text{A6.27})$$

Equations A6.25 and A6.26 are integrated and the constant of integration is determined for initial conditions given by *A_0 and *T_0 :

$$^*A/^*T = (1/a)(1-Z_0 \cdot F^{D-1} + A_0 \cdot a/F - 1/F + Z_0/F) \quad (A6.28)$$

$$^*B/^*T = (1/b)(1-Z_0 \cdot F^{D-1} + B_0 \cdot b/F - 1/F + Z_0/F) \quad (A6.29)$$

Eqns A6.25, A6.26, A6.27, A6.28 and A6.29 are inserted into eqn A6.24 to give:

$$\text{SLOPE} = \frac{b[1-D \cdot ((1-Z_0 \cdot F^{D-1} + A_0 \cdot a/F - 1/F + Z_0/F)/(1-D \cdot Z_0 \cdot F^{D-1}))]}{a[1-D \cdot ((1-Z_0 \cdot F^{D-1} + B_0 \cdot b/F - 1/F + Z_0/F)/(1-D \cdot Z_0 \cdot F^{D-1}))]} \quad (A6.30)$$

When $D=0$, equation A6.30 becomes $\text{SLOPE}(D=0) = b/a = d^*A/d^*B$.

$$\text{SLOPE-ANGLE ERROR} = \tan^{-1}(\text{SLOPE}) - \tan^{-1}(b/a) \quad (A6.31)$$

Fig. A6.5 shows graphs of SLOPE-ANGLE ERROR vs D for a reasonable range of values for the other variables, F , A_0 , B_0 , Z_0 , a and b .

Normalized Pearce ratios are $(A \cdot Z_0/Z)$. The error in normalized Pearce ratios (NPR) is determined as follows.

$$\text{NPR} = A \cdot Z_0/Z = (^*A/^*T)(^*Z_0/^*T_0)/(^*Z/^*T) = (^*A/^*Z)(^*Z_0/^*T_0) \quad (A6.32)$$

Substitution of eqn A6.20 into A6.32 yields:

$$\text{NPR} = (^*A/^*T_0)(^*T_0/^*T)^D \quad (A6.33)$$

If $D=0$ (and the element, Z , is therefore perfectly incompatible) then NPR is proportional to *A (as observed earlier). $\text{NPR}/(^*A/^*T_0)$ is graphed (Fig. A6.6) against values of D to provide an estimate of the degree of compatibility at which significant deviations from $\text{NPR}/(^*A/^*T_0)$ equals 1 occur.

Fig. A6.5 and A6.6 show the effect of limited compatibility on Pearce ratios and Pearce ratio diagrams. At low values of the bulk mineral/melt distribution coefficient, $D \leq 0.01$, the error is minimal for all crystallization intervals up to approximately 90% ($F = 0.1$). The error increases rapidly with increasing D but is generally tolerable up to $D = 0.1$. For instance, Fig. A6.6 shows that with small

$D \sim 0.1$, and 50% crystallization ($F=0.5$), the error in Pearce ratio will be in the 10% range, and that the slope-angle error on Pearce ratio diagrams will approach 10° , which considering other uncertainties (e.g. sampling, preparation, analysis) is considered acceptable.

A6.7 CONCLUSIONS

It has been shown that Pearce ratio diagrams allow for the accurate analysis of compositional losses and gains in a differentiating system. The selection of appropriate complex numerator variables simplifies the testing of differentiation models. Values of $A_i Z_0/Z_i$ remove the scaling caused by the choice of variable Z . Values of $(A_i(Z_0/Z_i) - A_j(Z_0/Z_j))$ permit mineral losses and gains to be determined by simple subtraction.

The error caused by non-incompatibility in the constant element is analyzed as a function of the distribution coefficient, D , and, the fraction of remaining liquid, F . The error was found to be insignificant for $D \leq 0.01$ and acceptable for values of D approaching 0.1 and $F \geq 0.5$.

Pearce ratio diagrams are useful in studies of fractionation, contamination, mineral stoichiometry, etc., that is, wherever compositional data are used and a variable can be modelled as constant in absolute abundance.

Fig. A6.1: Test of Pearce ratios diagrams using test data generated from an initial composition (point 0) by subtraction (points 1, 2, 3 and 4) or addition (points C1 and C2) of *A , *B , *C and *Z in the proportions 3:2:1:0, respectively (note that *Z will remain constant). The data slope of each graph gives the correct slope.

Fig. A6.2: Pearce ratio diagram using cation abundances. Data is from the Great Abitibi gabbro dyke, southern Superior Province (Ernst et al., 1987). Ba is the denominator variable and it is constant in total abundance. Reference vectors for possible minerals are shown. R is the resultant vector. The reference vectors are used to define a possible fractionation assemblage.

Fig. A6.3: Pearce ratio diagram using complex functions of the cation abundances of major elements as the numerator variables. Data are from the Great Abitibi dyke and Ba (in cation abundances) is used as the constant denominator variable.

Fig. A6.4: Geochemical data from one traverse across the Great Abitibi Dyke. 4A and 4C shows CIPW normative abundances. 4B and 4D shows normalized Pearce ratios which have been produced by multiplying CIPW abundances by Ba_0/Ba_j . The value for Ba_0 is from the most primitive chilled margin sample (circled data point).

Fig. A6.5: Plot of the error in the slope angle as a function of D for various values of F , A_0 , B_0 , Z_0 , a and b . See equation A6.31.

Fig. A6.6: Plot of normalized Pearce ratio vs bulk distribution coefficient, D , for various values of F . See equation A6.33.

APPENDIX 7: GEOCHEMICAL MAPS

A7.1 EXPLANATION OF MAPS

Regional variation in the whole-rock geochemistry of the Great Abitibi Dyke (GAD) is illustrated through a series of geochemical maps which are based on the data presented in Appendix 5. On these geochemical maps the across-dyke (width) scale is extremely exaggerated with respect to the along-dyke scale. The zero datum on the along-dyke scale is arbitrarily chosen, and is the same as in Fig. 1.2. The abundance of each variable is illustrated by the circle-size. Reference circles on each map give the maximum, mean and minimum abundances. The major element data were normalized to 100% (i.e. volatile free) before being plotted. On each map the region of unit 2 rocks is delimited by a pattern of closely-spaced parallel lines.

A7.2 SUMMARY OF OBSERVATIONS

A7.2.1 Introduction

The chemical information on these maps is summarized below under the following themes: incompatible elements, felsic silicates (plagioclase, alkali feldspar), mafic silicates (olivine, augite and orthopyroxene), iron-titanium oxides, apatite and LOI (loss on ignition). The maps are arranged in an order consistent with Table A5.1. The map order is: SiO_2 , TiO_2 , Al_2O_3 , $\text{Fe}_2\text{O}_3\text{T}$, MgO , CaO , Na_2O , K_2O , P_2O_5 , MnO , LOI, Zr, Y, Nb, Zn, Ba, Rb, Sr, V, Ni, Cr, Co, Ta, Sc, Yb, orthoclase, albite, anorthite, nepheline, clinopyroxene, orthopyroxene, olivine, magnetite, ilmenite, apatite, Mg* in clinopyroxene, Mg* in orthopyroxene and Mg* in olivine. The above listed minerals are all CIPW normative minerals.

A7.2.2 Incompatible Elements

Hf, Y and La abundances in unit 1 rocks increase towards the northeast end of the dyke. Only at traverse 15 do unit 1 samples exhibit a simple across-dyke variation. At this traverse, the following elements increase in abundance from the margin inwards: Hf, Nb and La. The elements, Ba, Rb, Th, K, Nb, Ta, La, Sm, Zr, Hf, Tb, Y, Yb, are more abundant in unit 2 than in unit 1 rocks. Variation in Nb, Y, Zr, Ba, Rb contents between unit 1 and unit 2 rocks is sharper on the south side of traverse 7 and is sharper on the north side of traverse 14.

A7.2.3 Felsic Minerals

The plagioclase concentration is reflected by normative anorthite, normative albite, Al_2O_3 and Sr. The concentration of plagioclase as interpreted from these variables remains approximately the same throughout unit 1 except at traverse 15 where the abundance of Al_2O_3 increases from the margin inwards. The plagioclase abundance in unit 2 rocks increases from the southwest to northeast along the dyke and approaches the plagioclase abundance in unit 1 samples at traverse 14.

Variation in the size of the europium anomaly (Eu/Eu^*) may also reflect changes in plagioclase abundance. The europium anomaly has a value greater than 1 throughout the GAD (the average = 1.2). The largest values with a maximum of 2.3, are found in near-margin samples from the southwest end of the GAD; these samples are probably plagioclase cumulates.

The alkali feldspar abundances are reflected by the abundance of normative orthoclase, Ba and K_2O , all of which have similar behaviour to other incompatible elements (section A7.2.2).

The variation in the albite component of plagioclase (as monitored by normative albite and Na_2O) has similarities to the variation both in plagioclase (anorthite plus albite) and in orthoclase.

The normative nepheline concentration is zero throughout most of the dyke. Some non-zero values are found in unit 1 samples near the dyke margin.

The SiO_2 contents of unit 1 and 2 rocks from the southwest end of the dyke are similar. However, while the SiO_2 content of unit 1 rocks remains relatively constant throughout the dyke, SiO_2 abundance in unit 2 rocks increases towards the northeast. SiO_2 content appears to correlate with total feldspar abundance.

The CaO content of unit 1 rocks is controlled mostly by anorthite content but also by augite abundance. CaO content is relatively homogeneous throughout the dyke. The CaO content of unit 2 is, however, generally lower than that of unit 1.

For most of the variables discussed above, the unit 1 - unit 2 transition is sharper on the north side at traverse 14 and on the south side at traverse 7.

A7.2.4 Mafic Silicates

The abundance of augite as monitored by normative diopside is relatively uniform throughout unit 1. At traverse 14, unit 2 rocks have the same abundance as unit 1 rocks. However, towards the southwest the augite concentration in unit 2 rocks progressively increases above that in unit 1 rocks.

The amount of normative orthopyroxene is low throughout most of the dyke.

Normative olivine contents are similar throughout unit 1. The concentrations in unit 2 are in general lower than those in unit 1. Normative olivine content in unit 2 rocks decreases towards the northeast.

The Mg/Fe ratio in mafic silicates is monitored by the normative ratio in clinopyroxene, olivine and orthopyroxene. CIPW calculations fix the Mg/Fe ratio in three silicates at the same value (e.g. Cox et al., 1979, p. 410) and this ratio is approximately constant throughout unit 1 and is generally lower in unit 2 rocks.

The MnO concentration of unit 1 rocks is relatively uniform throughout the dyke. However, at traverse 15 there may be a slight increase in MnO concentration from the margin of the dyke inwards. The concentration in unit 2 decreases towards the northeast such that at traverse 14, units 1 and 2 are indistinguishable in terms of MnO

content.

Ni tends to be most abundant in samples from the margins of unit 1 and at traverse 15 there is a slight decrease in Ni content from the margin inwards. Ni content is lower in unit 2 than in unit 1 rocks and varies with olivine abundance.

The Cr content is low throughout the dyke and in unit 2 has abundances below the detection limit. The absence of Cr in unit 2 reflects the more evolved nature of this interior pulse.

At traverse 15, the Sc concentration decreases from the margin inwards. The highest Sc concentrations are at the southwest end of unit 2 and decrease towards the northeast such that at traverse 14 the Sc contents in unit 2 rocks match with those of unit 1. The pattern of variation in Sc is similar to that of augite, which is a reasonable result since Sc is probably hosted in augite.

A7.2.5 Iron-Titanium Oxides

The normative magnetite content is relatively uniform throughout the dyke. Samples at the southeast end of unit 2 have a slightly higher normative magnetite content than is found elsewhere in the dyke.

Ilmenite content is monitored by normative ilmenite abundance, TiO₂ and V contents. Ilmenite abundances are similar in unit 1 and 2 rocks from the southwest end of the dyke. However, while ilmenite abundance remains relatively constant throughout the dyke, that in unit 2 rocks decreases slightly towards the northeast. The ridge of elevated values which surrounds unit 2, can be correlated at traverse 7 with unit 1b rocks. These samples are ilmenite cumulates.

The Zn abundance is similar throughout unit 1. However, Zn abundances in unit 2 at traverses 5 and 7 are enriched with respect to adjacent unit 1 samples. Zn is hosted in titanomagnetite.

A7.2.6 Apatite

The apatite content is monitored by normative apatite, P₂O₅ and Y. The apatite content is similar throughout all parts of unit 1. The apatite content of unit 2 decreases towards the northeast and at traverse 14 has abundances similar to that in adjacent unit 1 rocks.

A7.2.7 Loss-On-Ignition

The average loss on ignition is 0.9 %. Lowest values are in the margin of the GAD. The largest abundances are in slightly altered samples from the southwest end of the dyke.

A7.2.8 Summary

The most important observations from the geochemical maps are that:

- 1) Unit 1 becomes slightly more evolved towards the northeast
- 2) Unit 1 becomes slightly more evolved inwards from the margins
- 3) Unit 2 is more evolved than unit 1.
- 4) Unit 2 rocks becomes more enriched in feldspar and depleted in mafic mineral phases from the southwest towards the northeast ends of

unit 2.

Fig. A7.1

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Fig. A7.1

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Fig. A7.1

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Fig. A7.1

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Fig. A7.1

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Fig. A7.1

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Fig. A7.1

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Fig. A7.1 (continued) 490

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Fig. A7.1

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Fig. A7.1

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Fig. A7.1

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Fig. A7.1

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Fig. A7.1

Fig. A7.1

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Fig. A7.1

Fig. A7.1

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Fig. A7.1

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Fig. A7.1

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Fig. A7.1

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Fig. A7.1

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Fig. A7.1

Fig. A7.1

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Fig. A7.1

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Fig. A7.1

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Fig. A7.1

Fig. A7.1

CIPW ORTHOCLASE

15.06

7.44

2.70

400KM

200KM

0KM

110M

0M

-110M

(Continued on next page)

Fig. A7.1

(Continued on next page)

Fig. A7.1

CIPW CLINOPYROXENE

Fig. A7.1

(Continued on next page)

CIPW ORTHOPYROXENE

Fig. A7.1 (continued)

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Fig. A7.1

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Fig. A7.1

$\frac{\text{Mg}}{\text{Mg}+\text{Fe}}$ % (CIPW CLINOPYROXENE)

Fig. A7.1

(Continued on next page)

$\frac{\text{Mg}}{\text{Mg}+\text{Fe}}$ % (CIPW ORTHOPYROXENE)

Fig. A7.1

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APPENDIX 8: MAGNETIC DATA: ANALYTICAL PROCEDURE

A8.1 SAMPLING PREPARATION FOR AMS AND PALEOMAGNETIC ANALYSIS

The distribution of samples collected for paleomagnetic and AMS analysis is displayed in Fig. 1.3. Fresh samples were collected to avoid chemical remanent magnetization (CRM) components of recent origin. Samples were also collected from the sides of outcrops to reduce the risk of lightning-induced isothermal remanent magnetization (IRM).

Most samples were field-oriented with a sun compass as well as a with a magnetic compass. Sun compass readings are considered more reliable and were used to orient the samples during analysis. However, sixteen samples were field-oriented using a magnetic compass only. These comprise all samples from traverses 10, 11 and 15, and one sample (RE820909) from traverse 16. For 61 samples, sun compass readings were compared with magnetic readings to assess the orientation-error in these samples which were oriented using only a magnetic compass. The average difference between sun and magnetic compass readings was 3.4° with a standard deviation of 2.9° and a range of 0° - 12.8° . Therefore, those 16 samples which were field-oriented using only a magnetic compass are unlikely to be more than a few degrees misoriented. In the paleomagnetic and AMS analysis in Chapters 8 and 9, these 16 samples were given equal weighting to those oriented using a sun compass.

Both block samples and field-drilled cores were collected. Cores were drilled from the block samples and all cores were sliced into specimens which are approximately 2.2 cm long and 2.54 cm in diameter. This length to width ratio, 2.2/2.54, for specimens minimizes magnetic anisotropy caused by the cylindrical shape (Noltimier, 1971).

A8.2 ANISOTROPY OF MAGNETIC SUSCEPTIBILITY

The AMS fabric was determined on specimens which had been prepared as described in Section A8.1 and whose volume had been determined by water-displacement in a graduated cylinder. The AMS fabric was determined using the Kappabridge KLY-1, which measures the susceptibility (per unit volume) along 15 directions under a low intensity (80 A/m, i.e. approximately 1 oe.) alternating (970 Hz) field. A computer program (accompanying the KLY-1) ANISO 10 (Jelinek, 1976) calculates the best fit susceptibility ellipsoid and determines the orientation (declination and inclination), magnitude (K_1 , K_2 , K_3) and confidence intervals of its principal axes.

The accuracy of the technique was assessed by measuring a calibration sample consisting of a small ellipsoidal piece (with principal dimensions, 2, 1.5 and 1 mm) of transformer steel (highly permeable to magnetic fields) embedded in a plastic holder. The orientation of the principal susceptibility axes, K_1 , K_2 and K_3 obtained from measurement of this calibration sample matches with the orientations of the long, intermediate and short axes, respectively, of the piece of transformer steel.

Typically 3 specimens were measured from each sample and a two-tiered averaging procedure was performed. Data were first combined into sample means and then the sample means were combined into site means. All data were averaged according to the axis averaging procedure of Scheidegger (1965) and Mark (1973) which is used, for example, by Ellwood and Whitney (1980) and Park et al. (1988).

A8.3 PALEOMAGNETISM

The magnetization vectors from specimens (prepared as in Section A8.1) were measured on a Schoenstedt fluxgate magnetometer, DSM-1, with an operating sensitivity of about $1 \cdot 10^{-4}$ A/m. Three different magnetometers were used: one at the laboratory run by D. Dunlop and H. Halls, at Erindale College, University of Toronto and two at W. Fahrig's laboratory at the Geological Survey of Canada in Ottawa. Approximately 20 specimens were analyzed on the magnetometer in Toronto and the remaining ~200 specimens from 112 samples were measured at the Ottawa site. A comparison of analytical precision was made between the two Geological Survey of Canada units using 7 specimens. The directional results are identical. However, one unit gives consistently (ca. 7%) higher intensities. Since different specimens from the same sample can show a comparable range in intensity, no correction was made for differing sensitivities of the two DSM-1 units in Ottawa. The third DSM unit (from the U. of Toronto) is expected to be comparable in precision and no correction was made for data collected on it either.

A Schoenstedt Single-Axis demagnetizer (GSD-1) and a Schoenstedt Tumbler (GSD-5) modified to behave as a single axis demagnetizer were used for alternating field (AF) demagnetization. For thermal demagnetization, a Schoenstedt TSD-1 was used. This unit had been modified by the Geological Survey of Canada to ensure that the temperature gradient along the row of samples is low. The demagnetization temperatures are considered accurate to $\pm 50^\circ \text{C}$ (Buchan, pers. comm. 1988).

All thermal measurements were made in a magnetically shielded room at the Geological Survey of Canada, Ottawa. The room reduced the ambient strength of the earth's field from ca. 60000 nT to less than 500 nT (60000 gammas to <500 gammas). This was done to prevent acquisition of a viscous overprint in the time between each demagnetization step and the measurement of remanent direction. Some paleomagnetic workers have noted that specimens can acquire a viscous overprint in the earth's field when the magnetic moment had been reduced by thermal demagnetization to only a few percent of the original level (e.g. H. Halls, pers. comm. 1983).

A set of 16 representative specimens from 11 samples were analyzed using the AF demagnetization technique in the shielded room (these are samples labelled, BX82120103, BX86110102, BX86110202, BX86110302, BX86110401, BX86110501, BX86110402, BX86110502, BX86330301, BX86330401, BX86330501, BX86330502, BX86330402, BX86330302, BX86330203, BX86330103). The results from these were compared with the results from other specimens (not measured in the

shielded room) in order to identify whether any viscous overprint was acquired during AF demagnetization. No differences were observed.

Each specimen analyzed using the AF technique was generally demagnetized using at least 15 steps. The typical pattern was: NRM, 2.5, 5., 10, 15, 20, 25, 30, 35, 40, 50, 60 and 70 mT. Most samples were also measured at 80, 90 and 100 mT. After demagnetization at each level, the remanent magnetization vector was measured.

For each specimen the sequence of remanent magnetization vectors measured during progressive AF demagnetization was graphed both on a stereonet (equal area) and orthogonal plots (Zijderveld plots). Furthermore, for each specimen, all sequences of three or more magnetization vectors were analyzed by principal component analysis to determine the best fit vector and its uncertainty. This analysis was done using a modified version of a computer program provided by J. Kirschvink to H. Halls and described in Kirschvink (1981).

The best-fit direction characteristic of each specimen was chosen from those calculated (using principal component analysis) according to the following criteria. The best fit direction defined a linear segment (on a orthogonal plot) at the highest coercivities, maximized the number of data points used, and minimized directional uncertainty. The stereonet and orthogonal plots were useful in this regard.

A two-tiered analysis employed Fisherian (Fisher, 1953) statistics to determine site means; specimens were first combined into sample means, and then samples were combined to yield site means. The orientation of the best-fit magnetization direction for each sample was recalculated for a common geographic position before Fisherian averaging was done. This results in up to a 5° correction. Latitude 48.5 N and longitude 81.4 W (near Timmins, Ontario) was chosen as the common site. This correction was done so that data from different sites could be directly compared.

A8.4 MASS SUSCEPTIBILITY

The mass susceptibility was measured on a split of the geochemical samples (Fig. 1.2) which had been previously crushed to a coarse grain size. The bulk susceptibility of each sample was analyzed in small portions (about 0.03 kg each) and for each portion, both the susceptibility (on the KLY-1 susceptibility bridge) and the mass (on a sensitive balance) were measured. One to 2 kg were analyzed for each sample. The total susceptibility (sum of the susceptibility measured from each portion) was divided by total mass in order to derive mass susceptibility.

A8.5 DERIVATION OF DETAILED MAP OF THE GAD

A detailed map (map pocket) of the GAD was produced from aeromagnetic maps and outcrop data. In producing this map, the outcrop data were considered most reliable, followed in terms of reliability by the 1:20,000 aeromagnetic maps, and finally, the 1:63,360 maps. The data were compiled at a scale of 1:63,360 and photographically reduced to produce the final map. Dyke width as shown on the map is approximately correct.

For mapping purposes the dyke was assumed to be centred below the maximum of the aeromagnetic anomaly. This is justified given the steep magnetization direction (approximately 80°) and subvertical dip of the dyke.

The location of the dyke was determined using aeromagnetic maps of scale 1:63,360 (GSC, 1970a; 1970b; 1970c; 1970d; 1970e; 1969a; 1969b; 1969c; 1969d; 1968a; 1968b; 1965a; 1965b; 1965c; 1963a; 1963b; 1963c; 1963d; 1963e; 1957a; 1957b; 1957c; 1957d; 1957e; 1957f; 1957g; 1957h; 1957i; 1957j; 1957k; 1957l; 1951a; 1951b; 1951c); these maps were derived from data collected along flight lines flown at an altitude of 500 or 1000 ft with a line spacing of approximately a third of a mile (520 metres).

Where available, more detailed (1:20,000) aeromagnetic maps (MERQ, 1984a, 1984b, 1984c, 1981a, 1981b, 1977, 1976, 1972) and OGS, 1984, 1982) were used; these were derived from data collected along flight lines flown at an altitude of 120 metres with an average line spacing of 200 metres.

The dyke location and width was also constrained by outcrop data (MEKQ, 1984c (Lac Madeleine), 1981a, 1981b, 1977, 1976, 1972; Breaks, 1970; Chartrand, 1984; Hebert, 1983; Johnstone, 1987; Leahy, 1971, 1965; Milne, 1972; Picard, 1985; Pyke, 1982; Satterly, 1959).

A8.6 GROUND MAGNETIC PROFILES

Ground magnetic profiles were collected using a portable (total field) proton magnetometer.

APPENDIX 9: PALEOMAGNETIC AND AMS ANALYSES: DATA FROM SPECIMENS

A9.1 EXPLANATION OF TABLE A9.1

The DESCRIPTIONS of each specimen comprise the following: HOSTROCK, SATellite DYKElet, CHILLED MARGin, VOLATILE?, DYKE, all of which were defined in Appendix 5. ALONG POSition, ACROSS POSition., THICKNESS and TRAVERSE are defined in Appendix 3.

M(NRM) is NRM intensity in units of 10^{-3} A/m. DECLination(PALeomagnetic) and INClination(PALeomagnetic) are the declination and inclination of the characteristic paleomagnetic remanence direction. MEAN K is the mean bulk (volume) susceptibility given in 10^{-6} SI units. DEC.(K1) and INC.(K1) give the orientation of maximum principal axis of the AMS ellipsoid. DEC.(K2) and INC.(K2) give the orientation of the intermediate axis. DEC.(K3) and INC.(K3) give the orientation of the minimum axis. NORM. K1, NORM. K2 and NORM. K3 give the normalized lengths of the maximum, intermediate and minimum axes, respectively, of the AMS ellipsoid; these are normalized such that their sum equals 3.

Vertical lines in Table A9.1 separate all specimens from the same sample. Palcomagnetic directions are given for the sampling site locations; they have not been corrected to a common location as is true of the data in Appendix 10. Samples whose names begin with RE were collected by the author, while those whose names begin with BX were sampled by Dr. Ken Buchan of the Geological Survey of Canada.

Specimens RE8204161B, RE8204161C and RE8204161D, which are from a dykelet at traverse 4, correspond to geochemical sample RE820416B.

Table A9.1

SAMPLE#	RE84280311	RE84280312	RE84280411	RE84280412	RE84280111	RE84280112	RE84280211	RE84280212	RE84280311	RE84280312	RE84281111	RE84281112
DESCR IPT.	2	2	2	2	2	2	2	2	2	2	2	2
TRAVERSE#	167	167	167	167	167	167	167	167	167	167	167	167
ALONG. POS.	-25.30	-25.30	-20.75	-20.75	-14.10	-14.10	-8.75	-8.75	-0.95	-0.95	43.55	43.55
ACROSS POS.	88.50	88.50	88.50	88.50	88.50	88.50	88.50	88.50	88.50	88.50	88.50	88.50
THICKNESS	1411	1411	25581	32363	2444	1387	698	993	2041	2326	1643	1672
M (NRM)	259.9	274.8	264.6	248.7	264.5	276.1	289.1	278.0	277.7	283.0	1643	1672
DEC. (PAL.)	64.1	62.8	77.3	54.6	70.0	61.6	64.2	63.0	70.3	61.6	14005	13821
MEAN K	21064	17916	15850	19777	22970	13949	18508	253.0	22752	267.6	14005	13821
DEC. (K1)	223.8	224.6	70.1	210.1	63.6	69.2	253.0	219.3	233.3	267.6	340.4	161.8
INC. (K1)	30.4	4.5	26.7	33.0	1.9	12.2	1.3	29.8	4.8	14.9	2.8	11.2
DEC. (K2)	127.6	318.2	276.8	132.0	155.7	167.6	161.5	80.0	141.9	2.5	92.1	10.7
INC. (K2)	10.5	38.8	60.7	12.2	48.6	34.0	50.8	52.9	16.0	17.7	82.9	77.2
DEC. (K3)	20.6	129.0	165.9	24.5	332.0	322.4	344.1	321.3	339.6	139.9	250.0	233.0
INC. (K3)	57.5	50.9	11.5	54.2	53.3	39.1	39.1	20.0	73.2	66.5	73.2	6.5
NORM. K1	1.0330	1.0262	1.0164	1.0095	1.0293	1.0273	1.0110	1.0167	1.0295	1.0284	1.0109	1.0138
NORM. K2	0.9998	1.0093	1.0106	1.0026	0.9919	0.9948	1.0038	1.0039	1.0113	1.0027	1.0078	1.0049
NORM. K3	0.9672	0.9645	0.9730	0.9879	0.9788	0.9779	0.9832	0.9794	0.9591	0.9689	0.9814	0.9813

SAMPLE#	RE84281011	RE84281021	RE84281511	RE84281512	RE84281211	RE84281221	RE84281311	RE84281321
DESCR IPT.	2	2	2	2	2	2	2	2
TRAVERSE#	167	167	167	167	167	167	167	167
ALONG. POS.	43.75	43.75	50.25	50.25	52.95	52.95	53.75	53.75
ACROSS POS.	88.50	88.50	88.50	88.50	88.50	88.50	88.50	88.50
THICKNESS	13652	9396	1274	1259	5033	3543	1793	1240
M (NRM)	UNSTABLE	UNSTABLE	278.6	273.5	269.0	273.3	326.1	288.9
DEC. (PAL.)	UNSTABLE	UNSTABLE	64.4	63.2	50.3	61.0	72.1	70.4
MEAN K	8074	47420	47907	46963	67550	58530	44951	50710
DEC. (K1)	87.9	259.1	268.5	271.4	341.3	299.9	281.6	228.6
INC. (K1)	7.0	5.4	47.1	49.2	73.3	52.9	70.9	33.1
DEC. (K2)	357.6	71.2	41.9	44.2	81.5	47.5	47.5	25.9
INC. (K2)	2.3	84.5	32.5	30.4	3.0	34	11.5	54.7
DEC. (K3)	249.2	169.0	148.9	149.7	172.4	193.1	140.6	131.5
INC. (K3)	82.6	0.8	24.7	24.5	16.4	12.2	15.0	10.8
NORM. K1	1.0096	1.0147	1.0161	1.0136	1.0104	1.0070	1.0090	1.0110
NORM. K2	1.0301	1.0025	0.9957	0.9964	1.0011	1.0025	1.0055	1.0056
NORM. K3	0.9903	0.9828	0.9882	0.9900	0.9885	0.9905	0.9855	0.9834

(Continued on next page)

Table A9.1

SAMPLE#	REB4250111	REB4250112	REB4250111	REB4250112	REB4250111	REB4250112	REB4250111	REB4250112	REB4250111	REB4250112
DESCRPT.	HUSTROCK	HUSTROCK	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE
TRAVEL#	201	201	201	201	201	201	201	201	201	201
ALONG POS.	-78.25	-78.25	-72.00	-72.00	-57.00	-27.50	-27.50	-16.50	25.50	25.50
ACROSS POS.	148.50	148.50	148.50	148.50	148.50	148.50	148.50	148.50	148.50	148.50
THICKNESS	313	328	812	1342	1287	886	1101	814	851	839
M (NRM)	298.4	293.1	772.3	274.8	306.5	291.9	297.6	303.2	288.6	291.5
DEC. (PAL.)	56.2	57.6	71.6	47.3	61.3	50.2	50.1	44.5	47.5	44.8
INC. (PAL.)	7946	8989	48410	47190	10265	14114	13179	10501	17100	18771
MEAN K	233.2	239.8	275.6	272.1	312.2	9.2	21.7	112.2	278.6	239.3
DEC. (K1)	38.8	33.4	64.4	65.0	43.1	13.8	68.6	22.5	14.0	79.2
INC. (K1)	137.9	331.9	67.6	61.2	201.4	279.1	276.1	6.2	11.9	18.3
DEC. (K2)	6.5	3.1	22.9	21.8	20.8	0.5	6.0	33.6	12.7	8.2
INC. (K2)	40.0	66.6	162.2	155.9	112.6	187.2	183.9	228.3	142.6	109.3
DEC. (K3)	50.4	56.4	10.8	11.6	57.3	76.2	20.4	47.6	70.9	7.0
MEAN K1	1.0107	1.0141	1.0190	1.0201	1.0170	1.0239	1.0233	1.0204	1.0239	1.0134
NORM. K2	1.0021	0.981	1.0110	1.0109	1.0003	0.9982	1.0085	1.0076	1.0038	1.0060
NORM. K3	0.9873	0.9878	0.9700	0.9691	0.9827	0.9779	0.9882	0.9832	0.9703	0.9806

SAMPLE#	REB4250411	REB4250412	REB4250311	REB4250312	REB4250211	REB4250212	REB4250213	REB4250113	REB4250114
DESCRPT.	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE
TRAVEL#	201	201	201	201	201	201	201	201	201
ALONG POS.	29.75	29.75	39.25	39.25	54.50	54.50	54.50	56.65	56.65
ACROSS POS.	148.50	148.50	148.50	148.50	148.50	148.50	148.50	148.50	148.50
THICKNESS	1086	1411	531	545	706	596	61	465	465
M (NRM)	277.4	292.0	292.3	291.5	280.6	296.9	296.7	318.9	318.9
DEC. (PAL.)	45.1	47.4	44.8	44.8	50.5	44.8	44.8	76.7	76.7
INC. (PAL.)	20318	28905	20007	20578	20066	12572	18290	725.2	2390.5
MEAN K	301.6	16.5	94.9	95.7	197.4	42.9	54.7	297.4	214.0
DEC. (K1)	11.1	17.6	48.3	6.0	50.1	2.7	51.9	31.9	35.7
INC. (K1)	210.0	200.8	1.8	4.3	57.5	310.9	196.7	89.3	73.4
DEC. (K2)	8.0	72.4	2.8	13.2	32.6	35.4	27.7	54.8	47.1
INC. (K2)	84.8	106.9	269.4	209.4	313.7	136.7	300.2	198.9	319.6
DEC. (K3)	74.3	1.2	41.6	75.4	54.5	54.5	24.0	13.3	20.5
MEAN K1	1.0163	1.0106	1.0128	1.0272	1.0110	1.0339	1.0217	1.0056	1.0129
NORM. K2	0.9953	1.0055	0.9967	1.0211	0.9997	1.0071	0.9906	1.0025	1.0006
NORM. K3	0.9884	0.9839	0.9905	0.9517	0.9898	0.9590	0.9877	0.9919	0.9864

(Continued on next page)

Table A9.1

SAMPLE#	RE84240311	RE84240321	RE84240412	RE84240421	RE84240511	RE84240512	RE84240611	RE84240612	RE84240711	RE84240712	RE84240811	RE84240812	RE84240911	RE84240912	RE84241011	RE84241012	RE84241111	RE84241112	RE84241211	RE84241212	RE84241311	RE84241312	RE84241411	RE84241412	RE84241511	RE84241512	RE84241611	RE84241612	RE84241711	RE84241712	RE84241811	RE84241812	RE84241911	RE84241912	RE84242011	RE84242012		
DESCRPT.	TRVERSE#	ALONG. POS.	THICKNESS	M (MM)	DEC. (PAL.)	INC. (PAL.)	MEAN K	DEC. (K1)	INC. (K1)	DEC. (K2)	INC. (K2)	DEC. (K3)	MEAN K	NORM. K1	NORM. K2	NORM. K3																						
	206	206	206	206	206	206	206	206	206	206	206	206	206	206	206	206	206	206	206	206	206	206	206	206	206	206	206	206	206	206	206	206	206	206	206	206	206	
	-54.45	-54.45	-54.45	-54.45	-54.45	-54.45	-54.45	-54.45	-54.45	-54.45	-54.45	-54.45	-54.45	-54.45	-54.45	-54.45	-54.45	-54.45	-54.45	-54.45	-54.45	-54.45	-54.45	-54.45	-54.45	-54.45	-54.45	-54.45	-54.45	-54.45	-54.45	-54.45	-54.45	-54.45	-54.45	-54.45	-54.45	
	137.50	137.50	137.50	137.50	137.50	137.50	137.50	137.50	137.50	137.50	137.50	137.50	137.50	137.50	137.50	137.50	137.50	137.50	137.50	137.50	137.50	137.50	137.50	137.50	137.50	137.50	137.50	137.50	137.50	137.50	137.50	137.50	137.50	137.50	137.50	137.50	137.50	
	1015	966	1220	1636	1178	1027	282.9	275.0	275.0	275.0	275.0	275.0	275.0	275.0	275.0	275.0	275.0	275.0	275.0	275.0	275.0	275.0	275.0	275.0	275.0	275.0	275.0	275.0	275.0	275.0	275.0	275.0	275.0	275.0	275.0	275.0	275.0	
	53.0	56.7	53.6	56.6	55.5	51.2	47.1	42.5	47.1	42.5	47.1	42.5	47.1	42.5	47.1	42.5	47.1	42.5	47.1	42.5	47.1	42.5	47.1	42.5	47.1	42.5	47.1	42.5	47.1	42.5	47.1	42.5	47.1	42.5	47.1	42.5	47.1	
	16175	14433	16384	18747	21016	20243	20243	20243	20243	20243	20243	20243	20243	20243	20243	20243	20243	20243	20243	20243	20243	20243	20243	20243	20243	20243	20243	20243	20243	20243	20243	20243	20243	20243	20243	20243	20243	20243
	326.9	286.6	289.0	272.4	166.6	279.4	279.4	279.4	279.4	279.4	279.4	279.4	279.4	279.4	279.4	279.4	279.4	279.4	279.4	279.4	279.4	279.4	279.4	279.4	279.4	279.4	279.4	279.4	279.4	279.4	279.4	279.4	279.4	279.4	279.4	279.4	279.4	
	52.4	14.5	31.8	27.9	9.8	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	
	222.2	18.2	192.7	140.7	259.1	188.2	188.2	188.2	188.2	188.2	188.2	188.2	188.2	188.2	188.2	188.2	188.2	188.2	188.2	188.2	188.2	188.2	188.2	188.2	188.2	188.2	188.2	188.2	188.2	188.2	188.2	188.2	188.2	188.2	188.2	188.2	188.2	
	11.0	5.9	10.0	51.4	14.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	
	124.2	129.7	87.4	16.2	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7	
	35.5	74.3	56.3	24.3	72.7	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	78.2	
	1.0081	1.0039	1.0093	1.0047	1.0133	1.0126	1.0126	1.0126	1.0126	1.0126	1.0126	1.0126	1.0126	1.0126	1.0126	1.0126	1.0126	1.0126	1.0126	1.0126	1.0126	1.0126	1.0126	1.0126	1.0126	1.0126	1.0126	1.0126	1.0126	1.0126	1.0126	1.0126	1.0126	1.0126	1.0126	1.0126	1.0126	
	0.9998	1.0006	0.9958	0.9990	1.0073	1.0046	1.0046	1.0046	1.0046	1.0046	1.0046	1.0046	1.0046	1.0046	1.0046	1.0046	1.0046	1.0046	1.0046	1.0046	1.0046	1.0046	1.0046	1.0046	1.0046	1.0046	1.0046	1.0046	1.0046	1.0046	1.0046	1.0046	1.0046	1.0046	1.0046	1.0046	1.0046	
	0.9921	0.9955	0.9949	0.9963	0.9794	0.9828	0.9828	0.9828	0.9828	0.9828	0.9828	0.9828	0.9828	0.9828	0.9828	0.9828	0.9828	0.9828	0.9828	0.9828	0.9828	0.9828	0.9828	0.9828	0.9828	0.9828	0.9828	0.9828	0.9828	0.9828	0.9828	0.9828	0.9828	0.9828	0.9828	0.9828	0.9828	

SAMPLE#	RE84240101D	RE84240102B	RE84240102C	RE84240102D	RE84240102E	RE84240102F	RE84240102G	RE84240102H	RE84240102I	RE84240102J	RE84240102K	RE84240102L	RE84240102M	RE84240102N	RE84240102O	RE84240102P	RE84240102Q	RE84240102R	RE84240102S	RE84240102T	RE84240102U	RE84240102V	RE84240102W	RE84240102X	RE84240102Y	RE84240102Z	RE84240102A	RE84240102B	RE84240102C	RE84240102D	RE84240102E	RE84240102F	RE84240102G	RE84240102H	RE84240102I	RE84240102J	RE84240102K	RE84240102L	RE84240102M	RE84240102N	RE84240102O	RE84240102P	RE84240102Q	RE84240102R	RE84240102S	RE84240102T	RE84240102U	RE84240102V	RE84240102W	RE84240102X	RE84240102Y	RE84240102Z	RE84240102A	RE84240102B	RE84240102C	RE84240102D	RE84240102E	RE84240102F	RE84240102G	RE84240102H	RE84240102I	RE84240102J	RE84240102K	RE84240102L	RE84240102M	RE84240102N	RE84240102O	RE84240102P	RE84240102Q	RE84240102R	RE84240102S	RE84240102T	RE84240102U	RE84240102V	RE84240102W	RE84240102X	RE84240102Y	RE84240102Z	RE84240102A	RE84240102B	RE84240102C	RE84240102D	RE84240102E	RE84240102F	RE84240102G	RE84240102H	RE84240102I	RE84240102J	RE84240102K	RE84240102L	RE84240102M	RE84240102N	RE84240102O	RE84240102P	RE84240102Q	RE84240102R	RE84240102S	RE84240102T	RE84240102U	RE84240102V	RE84240102W	RE84240102X	RE84240102Y	RE84240102Z	RE84240102A	RE84240102B	RE84240102C	RE84240102D	RE84240102E	RE84240102F	RE84240102G	RE84240102H	RE84240102I	RE84240102J	RE84240102K	RE84240102L	RE84240102M	RE84240102N	RE84240102O	RE84240102P	RE84240102Q	RE84240102R	RE84240102S	RE84240102T	RE84240102U	RE84240102V	RE84240102W	RE84240102X	RE84240102Y	RE84240102Z	RE84240102A	RE84240102B	RE84240102C	RE84240102D	RE84240102E	RE84240102F	RE84240102G	RE84240102H	RE84240102I	RE84240102J	RE84240102K	RE84240102L	RE84240102M	RE84240102N	RE84240102O	RE84240102P	RE84240102Q	RE84240102R	RE84240102S	RE84240102T	RE84240102U	RE84240102V	RE84240102W	RE84240102X	RE84240102Y	RE84240102Z	RE84240102A	RE84240102B	RE84240102C	RE84240102D	RE84240102E	RE84240102F	RE84240102G	RE84240102H	RE84240102I	RE84240102J	RE84240102K	RE84240102L	RE84240102M	RE84240102N	RE84240102O	RE84240102P	RE84240102Q	RE84240102R	RE84240102S	RE84240102T	RE84240102U	RE84240102V	RE84240102W	RE84240102X	RE84240102Y	RE84240102Z	RE84240102A	RE84240102B	RE84240102C	RE84240102D	RE84240102E	RE84240102F	RE84240102G	RE84240102H	RE84240102I	RE84240102J	RE84240102K	RE84240102L	RE84240102M	RE84240102N	RE84240102O	RE84240102P	RE84240102Q	RE84240102R	RE84240102S	RE84240102T	RE84240102U	RE84240102V	RE84240102W	RE84240102X	RE84240102Y	RE84240102Z	RE84240102A	RE84240102B	RE84240102C	RE84240102D	RE84240102E	RE84240102F	RE84240102G	RE84240102H	RE84240102I	RE84240102J	RE84240102K	RE84240102L	RE84240102M	RE84240102N	RE84240102O	RE84240102P	RE84240102Q	RE84240102R	RE84240102S	RE84240102T	RE84240102U	RE84240102V	RE84240102W	RE84240102X	RE84240102Y	RE84240102Z	RE84240102A	RE84240102B	RE84240102C	RE84240102D	RE84240102E	RE84240102F	RE84240102G	RE84240102H	RE84240102I	RE84240102J	RE84240102K	RE84240102L	RE84240102M	RE84240102N	RE84240102O	RE84240102P	RE84240102Q	RE84240102R	RE84240102S	RE84240102T	RE84240102U	RE84240102V	RE84240102W	RE84240102X	RE84240102Y	RE84240102Z	RE84240102A	RE84240102B	RE84240102C	RE84240102D	RE84240102E	RE84240102F	RE84240102G	RE84240102H	RE84240102I	RE84240102J	RE84240102K	RE84240102L	RE84240102M	RE84240102N	RE84240102O	RE84240102P	RE84240102Q	RE84240102R	RE84240102S	RE84240102T	RE84240102U	RE84240102V	RE84240102W	RE84240102X	RE84240102Y	RE84240102Z	RE84240102A	RE84240102B	RE84240102C	RE84240102D	RE84240102E	RE84240102F	RE84240102G	RE84240102H	RE84240102I	RE84240102J	RE84240102K	RE84240102L	RE84240102M	RE84240102N	RE84240102O	RE84240102P	RE84240102Q	RE84240102R	RE84240102S	RE84240102T	RE84240102U	RE84240102V	RE84240102W	RE84240102X	RE84240102Y	RE84240102Z	RE84240102A	RE84240102B	RE84240102C	RE84240102D	RE84240102E	RE84240102F	RE84240102G	RE84240102H	RE84240102I	RE84240102J	RE84240102K	RE84240102L	RE84240102M	RE84240102N	RE84240102O	RE84240102P	RE84240102Q	RE84240102R	RE84240102S	RE84240102T	RE84240102U	RE84240102V	RE84240102W	RE84240102X	RE84240102Y	RE84240102Z	RE84240102A	RE84240102B	RE84240102C	RE84240102D	RE84240102E	RE84240102F	RE84240102G	RE84240102H	RE84240102I	RE84240102J	RE84240102K	RE84240102L	RE84240102M	RE84240102N	RE84240102O	RE84240102P	RE84240102Q	RE84240102R	RE84240102S	RE84240102T	RE84240102U	RE84240102V	RE84240102W	RE84240102X	RE84240102Y	RE84240102Z	RE84240102A	RE84240102B	RE84240102C	RE84240102D	RE84240102E	RE84240102F	RE84240102G	RE84240102H	RE84240102I	RE84240102J	RE84240102K	RE84240102L	RE84240102M	RE84240102N	RE84240102O	RE84240102P	RE84240102Q	RE84240102R	RE84240102S	RE84240102T	RE84240102U	RE84240102V	RE84240102W	RE84240102X	RE84240102Y	RE84240102Z	RE84240102A	RE84240102B	RE84240102C	RE84240102D	RE84240102E	RE84240102F	RE84240102G	RE84240102H	RE84240102I	RE84240102J	RE84240102K	RE84240102L	RE84240102M	RE84240102N	RE84240102O	RE84240102P	RE84240102Q	RE84240102R	RE84240102S	RE84240102T	RE
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Table A9.1

SAMPLE#	REB2042022	REB2042111	REB2042112
DESCRPT.	SAT. DYKE	SAT. DYKE	SAT. DYKE
TRAVERSE#	4	4	4
A LONG. POS.	206	206	206
A CROSS. POS.	68.75	68.75	68.75
THICKNESS	137.50	137.50	137.50
M (NEM)	319	1020	1645
DEC. (PAL.)	278.4	296.3	287.4
INC. (PAL.)	55.9	65.9	64.4
MEAN K	44269	42240	50110
DEC. (K1)	6.6	304.3	301.8
INC. (K1)	1.7	53.9	48.5
DEC. (K2)	96.9	75.4	61.6
INC. (K2)	10.7	25.6	23.7
DEC. (K3)	267.9	177.5	167.4
INC. (K3)	79.2	23.6	11.7
NORM. K1	1.0093	1.0234	1.0300
NORM. K2	1.0070	1.0038	1.0061
NORM. K3	0.9837	0.9707	0.9639

SAMPLE#
DESCRPT.
TRAVERSE#
A LONG. POS.
A CROSS. POS.
THICKNESS
M (NEM)
DEC. (PAL.)
INC. (PAL.)
MEAN K
DEC. (K1)
INC. (K1)
DEC. (K2)
INC. (K2)
DEC. (K3)
INC. (K3)
NORM. K1
NORM. K2
NORM. K3

Table A9.1

SAMPLE#	REB4015112	REB4015113	REB4015011	REB4015012	REB4014912	REB4014913	REB4014811	REB4014812	REB4015211	REB4015212	REB4014711	REB4014712
DESCRPT.	HUSTROCK	HUSTROCK	HUSTROCK	HUSTROCK	HUSTROCK	HUSTROCK	HUSTROCK	HUSTROCK	HUSTROCK	HUSTROCK	CHIL..MAR.	CHIL..MAR.
TRAVERSE#	7	7	7	7	7	7	7	7	7	7	7	7
ALONG. POS.	243	243	243	243	243	243	243	243	243	243	243	243
ACROSS POS.	-137.75	-137.75	-133.50	-133.50	-117.25	-117.25	-108.40	-108.40	-104.75	-104.75	-104.75	-104.75
THICKNESS	209.50	209.50	209.50	209.50	209.50	209.50	209.50	209.50	209.50	209.50	209.50	209.50
M(NUM)	87	61	11	59	109	94		1	313	315	1403	984
DEC.(PAL.)	332.3	350.5	153.4	UNSTABLE	269.6	263.5		302.4	279.2	296.1	336.8	328.1
INC.(PAL.)	78.3	75.3	74.4		62.7	67.3		64.3	67.9	70.9	58.0	50.9
MEAN K												
UNC.(K1)												
INC.(K1)												
DEC.(K2)												
INC.(K2)												
DEC.(K3)												
INC.(K3)												
NORM. K1												
NORM. K2												
NORM. K3												

SAMPLE#	REB4012511	REB4012512	REB4012513	REB4012611	REB4012612	REB4012613	REB4013011	REB4013012	REB4013013	REB4012711	REB4012712	REB4012713
DESCRPT.	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE
TRAVERSE#	7	7	7	7	7	7	7	7	7	7	7	7
ALONG. POS.	243	243	243	243	243	243	243	243	243	243	243	243
ACROSS POS.	-101.45	-101.45	-101.45	-92.35	-92.35	-92.35	-75.35	-75.35	-75.35	-60.25	-60.25	-60.25
THICKNESS	209.50	209.50	209.50	209.50	209.50	209.50	209.50	209.50	209.50	209.50	209.50	209.50
M(NUM)	385	534	757	6386	2465	2370	2170	1565	2150	1546	1112	
DEC.(PAL.)	304.9	308.5		298.5	UNSTABLE	278.0	278.0	328.5		289.6	301.9	
INC.(PAL.)	64.5	71.5		83.6	77.1	77.1	77.1	76.3		295.78	20350	
MEAN K	9659	11863		9545	7844	39900	39900	31580		75.4	74.6	27962
DEC.(K1)	176.1	10.8		359.1	248.4	68.2	69.0	103.5		79.1	79.1	
INC.(K1)	1.7	3.6		18.0	32.2	18.7	48.7	37.8		34.0	33.8	15.9
DEC.(K2)	266.1	101.9		260.7	3.3	185.5	198.1	13.7		239.2	231.0	194.0
INC.(K2)	2.5	16.5		24.2	33.8	53.5	28.9	2.2		34.9	53.9	55.9
DEC.(K3)	51.5	268.9		121.9	126.9	326.9	304.2	280.8		340.2	336.9	339.9
INC.(K3)	87.0	73.1		59.1	39.6	30.1	26.6	52.1		7.6	11.3	29.2
NORM. K1	1.0234	1.0218		1.0163	1.0231	1.0263	1.0299	1.0386		1.0127	1.0146	1.0109
NORM. K2	1.0001	1.0070		1.0114	1.0168	1.0218	1.0084	1.0205		1.0001	0.9967	1.0023
NORM. K3	0.9766	0.9712		0.9723	0.9601	0.9519	0.9617	0.9409		0.9872	0.9887	0.9869

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Table A9.1

SAMPLE#	REB4012811	REB4012812	REB4012813	REB4012911	REB4012912	REB4012913	REB4012914	REB4014511	REB4014512	REB4014513	REB4013111	REB4013112
DESCRIPTION	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE
TRAVEL	7	7	7	7	7	7	7	7	7	7	7	7
ALONG POS.	243	243	243	243	243	243	243	243	243	243	243	243
ACROSS POS.	-49.75	-49.75	-49.75	-40.55	-40.55	-40.55	-40.55	-32.95	-32.95	-32.95	-20.60	-20.60
THICKNESS	209.50	209.50	209.50	209.50	209.50	209.50	209.50	209.50	209.50	209.50	209.50	209.50
M (NRH)	1194	1194	1194	1400	1400	1477	1477	2267	1615	1989	1743	1743
DEC. (PAL.)	296.6	302.2	298.1	298.1	298.2	293.4	298.4	299.2	298.8	290.5	286.6	286.6
INC. (PAL.)	68.1	65.0	66.1	66.1	64.4	62.0	62.0	73.5	67.3	70.6	71.1	71.1
MEAN K	28576	24208	25800	28340	28340	29043	29499	27811	31597	37098	34722	34722
DEC. (K1)	254.5	237.2	66.4	246.4	246.4	257.9	62.7	69.5	249.3	67.7	72.5	70.8
INC. (K1)	24.4	22.6	11.0	8.0	8.0	2.2	13.0	7.7	9.3	7.8	31.9	38.4
DEC. (K2)	145.1	139.2	319.2	333.2	333.2	353.3	282.7	330.2	359.1	297.4	218.3	221.5
INC. (K2)	36.1	18.6	36.8	61.2	67.9	67.9	73.3	49.7	64.3	78.0	47.7	47.7
DEC. (K3)	370.5	373.5	163.1	154.2	167.0	167.0	155.1	165.9	155.2	158.9	331.7	328.6
INC. (K3)	44.0	60.1	30.9	27.4	22.0	22.0	10.4	39.3	23.7	9.0	16.7	15.0
NUM. K1	1.0176	1.0171	1.0245	1.0136	1.0136	1.0115	1.0124	1.0139	1.0128	1.0149	1.0137	1.0110
NUM. K2	0.9955	0.9944	0.9950	1.0008	1.0008	1.0006	1.0021	0.9993	0.9997	0.9983	1.0011	1.0077
NUM. K3	0.9970	0.9885	0.9805	0.9856	0.9856	0.9879	0.9855	0.9868	0.9875	0.9868	0.9852	0.9813

SAMPLE#	REB4013111	REB4013211	REB4013212	REB4013213	REB4013311	REB4013312	REB4013313	REB4013411	REB4013412	REB4013413	REB4013511	REB4013512
DESCRIPTION	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE
TRAVEL	7	7	7	7	7	7	7	7	7	7	7	7
ALONG POS.	243	243	243	243	243	243	243	243	243	243	243	243
ACROSS POS.	-20.60	-13.35	-13.35	-13.35	-1.25	-1.25	-1.25	11.50	11.50	11.50	25.05	25.05
THICKNESS	209.50	209.50	209.50	209.50	209.50	209.50	209.50	209.50	209.50	209.50	209.50	209.50
M (NRH)	1240	2079	1983	2142	2142	2086	2086	1901	1807	1510	2680	2208
DEC. (PAL.)	284.3	279.8	279.8	278.7	278.7	288.4	288.4	302.5	300.1	278.1	280.6	280.6
INC. (PAL.)	69.2	67.1	67.1	71.0	71.0	74.8	74.8	72.4	73.1	72.0	73.0	73.0
MEAN K	29496	28412	28412	40668	40668	40360	37460	36679	36119	40313	40440	40440
DEC. (K1)	83.0	76.7	77.3	67.3	67.3	67.5	66.5	83.2	79.2	59.5	190.2	190.2
INC. (K1)	19.4	19.6	7.1	13.6	13.6	24.1	12.3	35.3	23.0	0.2	36.7	36.7
DEC. (K2)	284.8	271.6	193.2	169.3	169.3	159.9	165.6	218.4	196.1	149.7	76.5	76.5
INC. (K2)	69.3	69.3	74.0	40.7	40.7	5.2	35.9	45.1	46.8	48.4	30.2	30.2
DEC. (K3)	175.5	168.4	168.4	322.8	322.8	261.2	320.6	334.9	332.5	329.2	316.8	316.8
INC. (K3)	7.1	4.8	4.8	14.2	14.2	63.3	31.4	24.0	34.2	41.6	38.6	38.6
NUM. K1	1.0162	1.0136	1.0090	1.0140	1.0140	1.0124	1.0090	1.0183	1.0152	1.0119	1.0071	1.0044
NUM. K2	0.9972	0.9972	0.9959	0.9962	0.9962	0.9993	1.0000	1.0006	0.9994	1.0035	1.0044	1.0044
NUM. K3	0.9865	0.9892	0.9892	0.9910	0.9899	0.9893	0.9910	0.9811	0.9854	0.9894	0.9837	0.9837

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Table A9.1

SAMPLE#	RE84013513	RE84013611	RE84013612	RE84013613	RE84013711	RE84013712	RE84013713	RE84013811	RE84013812	RE84013813	RE84014011	RE84014012
DESCRPT.	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE
TRAVERSE#	7	7	7	7	7	7	7	7	7	7	7	7
ALONG POS.	243	243	243	243	243	243	243	243	243	243	243	243
ACROSS POS.	25.05	38.95	38.95	38.95	62.25	62.25	62.25	75.75	75.75	75.75	90.60	90.60
THICKNESS	209.50	209.50	209.50	209.50	209.50	209.50	209.50	209.50	209.50	209.50	209.50	209.50
M (NRM)	2000	1768	2026	2026	2329	2031	2031	1329	1431	1160	2375	1971
DEC. (PAL.)	285.4	279.8	279.8	279.8	286.3	295.7	295.7	277.8	291.6	291.6	323.9	319.9
INC. (PAL.)	67.8	66.4	66.4	66.4	72.5	69.6	69.6	72.7	74.5	74.5	60.3	65.8
MEAN K	31833	36120	36120	36003	51307	55404	49259	23739	26381	26381	14821	15282
UEC. (K1)	174.9	99.4	99.4	67.7	56.7	229.8	64.1	260.0	104.8	104.8	325.0	344.3
INC. (K1)	29.1	68.7	68.7	14.9	15.2	8.4	29.7	1.0	21.2	21.2	1.4	3.7
DEC. (K2)	72.2	241.2	241.2	169.1	162.1	131.7	185.6	169.2	202.0	202.0	234.2	253.2
INC. (K2)	21.4	17.0	17.0	16.7	47.7	43.8	42.5	36.9	17.9	17.9	28.1	16.2
DEC. (K3)	311.4	335.0	335.0	319.6	312.3	328.3	312.3	351.3	328.7	328.7	57.6	86.9
INC. (K3)	52.5	12.4	12.4	49.4	33.1	44.9	33.1	53.1	61.7	61.7	61.8	73.3
NORM. K1	1.0062	1.0117	1.0117	1.0055	1.0097	1.0111	1.0110	1.0277	1.0152	1.0152	1.0245	1.0255
NORM. K2	1.0048	1.0008	1.0008	1.0031	1.0013	1.0000	1.0027	0.9935	1.0049	1.0049	0.9919	0.9995
NORM. K3	0.9890	0.9874	0.9874	0.9913	0.9890	0.9889	0.9863	0.9788	0.9799	0.9799	0.9836	0.9751

SAMPLE#	RE84014013	RE84014211	RE84014212	RE84014213	RE84014311	RE84014312
DESCRPT.	DYKE	DYKE	DYKE	DYKE	SAT. DYKE	SAT. DYKE
TRAVERSE#	7	7	7	7	7	7
ALONG POS.	243	243	243	243	243	243
ACROSS POS.	90.60	98.85	98.85	98.85	114.45	114.45
THICKNESS	209.50	209.50	209.50	209.50	209.50	209.50
M (NRM)	2000	2252	1313	1250	3070	3002
DEC. (PAL.)	296.2	288.1	288.1	288.1	262.4	278.7
INC. (PAL.)	72.6	68.5	68.5	68.5	73.3	71.6
MEAN K	14461	23395	20862	20862		
DEC. (K1)	166.7	176.8	177.2	177.2		
INC. (K1)	6.8	36.1	2.0	2.0		
DEC. (K2)	70.7	316.5	86.6	86.6		
INC. (K2)	40.8	46.3	16.0	16.0		
DEC. (K3)	264.4	70.4	274.0	274.0		
INC. (K3)	48.4	21.1	73.8	73.8		
NORM. K1	1.0212	1.0114	1.0043	1.0043		
NORM. K2	0.9968	0.9993	1.0008	1.0008		
NORM. K3	0.9820	0.9893	0.9949	0.9949		

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Table A9.1

SAMPLE#	BX86110501	BX86110502	BX86110503	BX86110601	BX86110602	BX86110603	BX86110701	BX86110702	BX86110703	BX86110701	BX86110702	BX86110703	BX86110701	BX86110702	BX86110703
DESCRPT.	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE
TRAVERS#	7"	7"	7"	7"	7"	7"	7"	7"	7"	7"	7"	7"	7"	7"	7"
ALONG. POS.	265	265	265	265	265	265	265	265	265	265	265	265	265	265	265
ACROSS POS.	-15.00	-15.00	-15.00	-14.00	-14.00	-14.00	-9.00	-9.00	-9.00	-9.00	-4.00	-4.00	-4.00	-4.00	-4.00
THICKNESS	231.00	231.00	231.00	231.00	231.00	231.00	231.00	231.00	231.00	231.00	231.00	231.00	231.00	231.00	231.00
M (NRM)	1008	996		713	1307		1115	1342		1657	1326				
DEC. (PAL.)	307.1	311.8		280.4	304.6		304.6	287.5		286.3	306.1				
INC. (PAL.)	61.0	61.5		69.5	64.1		64.1	65.0		67.9	64.4				
MEAN K	214.71	231.92		157.43	145.99		18386	19274		24182	20339				20036
DEC. (K1)	261.3	85.4	65.4	251.1	205.7		249.9	262.0		161.1	283.4				240.8
INC. (K1)	13.3	7.6	14.0	33.8	15.7		8.4	15.5		38.4	53.8				11.8
DEC. (K2)	51.9	206.0	306.0	66.0	59.0		131.3	163.6		59.3	50.7				115.6
INC. (K2)	74.8	75.4	63.1	56.1	72.4		45.5	27.9		14.6	24.0				70.0
DEC. (K3)	169.6	353.7	161.3	159.5	174.5		347.9	17.7		312.5	352.9				374.2
INC. (K3)	7.2	12.5	22.5	2.3	7.8		43.3	57.5		47.9	25.4				15.8
NORM. K1	1.0101	1.0077	1.0103	1.0134	1.0187		1.0158	1.0303		1.0277	1.0123				1.0163
NORM. K2	1.0016	1.0016	1.0011	0.9999	1.0014		1.0015	0.9901		0.9980	1.0086				1.0006
NORM. K3	0.9983	0.9907	0.9886	0.9967	0.9779		0.9819	0.9796		0.9743	0.9791				0.9831

SAMPLE#	BX86110101	BX86110102	BX86110103
DESCRPT.	DYKE	DYKE	DYKE
TRAVERS#	7"	7"	7"
ALONG. POS.	265	265	265
ACROSS POS.	0.00	0.00	0.00
THICKNESS	231.00	231.00	231.00
M (NRM)	769	953	
DEC. (PAL.)	299.8	295.5	
INC. (PAL.)	65.2	63.0	
MEAN K	18466	251.78	20630
DEC. (K1)	123.1	272.8	275.7
INC. (K1)	14.4	33.2	21.5
DEC. (K2)	25.9	43.9	42.6
INC. (K2)	26.0	45.1	36.3
DEC. (K3)	239.2	163.9	161.7
INC. (K3)	59.7	26.4	45.9
NORM. K1	1.0116	1.0235	1.0157
NORM. K2	0.9975	1.0052	1.0118
NORM. K3	0.9919	0.9713	0.9726

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Table A9.1

SAMPLE#	BR82160501	BR82160502	BR82160503
DESCRIPT.	DYKE	DYKE	DYKE
TRAVERSE#	9	9	9
ALONG. POS.	320	320	320
ACROSS POS.	0.00	0.00	0.00
THICKNESS	186.00	186.00	186.00
M (MM)	649	719	
DEC. (PAL.)	283.8	272.5	
INC. (PAL.)	67.7	63.0	
MEAN K	31348	33961	33004
DEC. (K1)	102.5	69.5	160.3
INC. (K1)	62.1	68.1	2.1
DEC. (K2)	350.9	183.1	66.5
INC. (K2)	11.1	9.2	60.4
DEC. (K3)	255.6	276.5	251.5
INC. (K3)	25.3	19.7	29.5
MINM. K1	1.0097	1.0124	1.0100
MINM. K2	0.9969	0.9994	0.9981
MINM. K3	0.9934	0.9882	0.9918

SAMPLE#
 DESCRIPT.
 TRAVERSE#
 ALONG. POS.
 ACROSS POS.
 THICKNESS
 M (MM)
 DEC. (PAL.)
 INC. (PAL.)
 MEAN K
 DEC. (K1)
 INC. (K1)
 DEC. (K2)
 INC. (K2)
 DEC. (K3)
 INC. (K3)
 MINM. K1
 MINM. K2
 MINM. K3

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Table A9.1

SAMPLE#	RES2130101	RES2130102	RES2130201	RES2130202	RES2130301	RES2130302	RES2130402	RES2020111	RES2020112	RES2020113	RES202041A
DESCR(PT.)	HYBRID	HYBRID	HYBRID	HYBRID	HYBRID	HYBRID	HYBRID	HYBRID	HYBRID	HYBRID	HYBRID
TRAVERSE#	10	10	10	10	10	10	10	10	10	10	10
ALONG. POS.	330	330	330	330	330	330	330	330	330	330	330
ACROSS POS.	-93.28	-102.00	-102.00	-102.00	-102.00	-102.00	-102.00	-93.28	-93.28	-93.28	-93.28
THICKNESS	186.56	186.56	186.56	186.56	186.56	186.56	186.56	186.56	186.56	186.56	186.56
M(NEM)	224	692	692	692	854	854	854	55	55	55	194
DEC.(PAL.)	299.1	327.1	299.9	299.7	291.6	308.2	302.0	UNSTABLE	338.7	338.7	UNSTABLE
INC.(PAL.)	74.9	77.2	73.7	72.2	75.9	75.4	77.4		11.4	11.4	80.5
MEAN K											
DEC.(K1)											
INC.(K1)											
DEC.(K2)											
INC.(K2)											
DEC.(K3)											
INC.(K3)											
NORM. K1											
NORM. K2											
NORM. K3											

SAMPLE#	RES202041B	RES202061B	RES202062A	RES2020711	RES2020712	RES2020723	RES2020921	RES2020922	RES2120101	RES2120102	RES2120103	RES2120301
DESCR(PT.)	HYBRID	HYBRID	HYBRID	HYBRID	HYBRID	HYBRID	HYBRID	HYBRID	HYBRID	HYBRID	HYBRID	HYBRID
TRAVERSE#	10	10	10	10	10	10	10	10	10	10	10	10
ALONG. POS.	330	330	330	330	330	330	330	330	330	330	330	330
ACROSS POS.	-93.28	-93.28	-93.28	-93.28	-93.28	-93.28	-93.28	-93.28	-93.28	-93.28	-93.28	-93.28
THICKNESS	186.56	186.56	186.56	186.56	186.56	186.56	186.56	186.56	186.56	186.56	186.56	186.56
M(NEM)	224	184	68	736	965	28	28	17	2152	2152	2584	1230
DEC.(PAL.)	UNSTABLE	334.7	347.9	337.4	291.6	297.2	297.2	306.2	314.9	314.9	321.8	307.2
INC.(PAL.)		68.5	70.4	73.3	71.3	69.0	69.0	56.7	76.7	76.7	77.3	79.0
MEAN K												
DEC.(K1)									23055	23440	21857	18771
INC.(K1)									251.6	266.5	240.8	243.9
DEC.(K2)									28.5	59.7	28.8	37.8
INC.(K2)									38.9	49.7	126.6	37.3
DEC.(K3)									57.1	25.7	36.8	49.2
INC.(K3)									153.3	167.1	358.1	142.7
NORM. K1									14.9	15.1	39.8	12.9
NORM. K2									1.0076	1.0059	1.0098	1.0233
NORM. K3									0.9946	1.0045	0.9978	1.0116
									0.9929	0.9896	0.9924	0.9651

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Table A9.1

SAMPLE#	BK82110102	BK82110101	BK82110102	BK82110201	BK82110202	BK82110301
DESCRPT.	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE
TRAVEL	10	10	10	10	10	10
ALONG. POS.	330	330	330	330	330	330
ACROSS POS.	-82.58	-82.58	-82.58	-82.58	-82.58	-82.58
THICKNESS	186.56	186.56	186.56	186.56	186.56	186.56
M (NOM)	1274	1292	1030	419	319.9	302.6
DEC. (PAL.)	321.2	311.3	307.3	72.3	72.3	59.9
INC. (PAL.)	79.3	75.6	73.8	68.1	68.1	54.39
MEAN K	16963	24084	27178	17982	21046	19469
DEC. (K1)	300.3	51.6	51.6	17.8	50.5	55.2
INC. (K1)	83.2	2.9	7.2	39.9	24.3	20.7
DEC. (K2)	64.8	204.3	174.4	108.4	175.9	90.8
INC. (K2)	3.8	84.3	76.8	0.7	52.0	16.2
DEC. (K3)	155.2	328.2	320.2	199.2	307.0	215.9
INC. (K3)	5.6	11.0	11.0	50.1	27.2	61.8
WORM. K1	1.0176	1.0098	1.0088	1.0121	1.0108	1.0128
WORM. K2	1.0142	1.0039	1.0025	1.0042	0.9980	0.9957
WORM. K3	0.9681	0.9862	0.9886	0.9784	0.9859	0.9894

SAMPLE#	BK82100102	BK82100101	BK82100103	BK82100201	BK82100202	BK82100301
DESCRPT.	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE
TRAVEL	10	10	10	10	10	10
ALONG. POS.	330	330	330	330	330	330
ACROSS POS.	-82.58	-82.58	-82.58	-82.58	-82.58	-82.58
THICKNESS	186.56	186.56	186.56	186.56	186.56	186.56
M (NOM)	411	449	502	684	577	727
DEC. (PAL.)	316.4	294.6	328.6	310.5	331.6	348.8
INC. (PAL.)	81.0	65.5	67.7	78.9	77.1	62.4
MEAN K	16452	19086	23280	21793	20432	22554
DEC. (K1)	10.4	42.0	207.1	93.1	120.9	81.7
INC. (K1)	21.8	13.6	18.5	25.1	32.9	23.9
DEC. (K2)	117.5	329.9	104.7	205.4	211.2	185.1
INC. (K2)	36.3	34.8	32.7	38.0	38.4	22.7
DEC. (K3)	256.2	149.9	321.7	339.4	301.8	317.2
INC. (K3)	45.6	51.9	51.2	40.6	57.1	52.0
WORM. K1	1.0144	1.0167	1.0186	1.0258	1.0190	1.0342
WORM. K2	1.0134	1.0120	1.0119	1.0150	1.0042	1.0061
WORM. K3	0.9836	0.9699	0.9727	0.9775	0.9768	0.9897

(Continued on next page)

Table A9.1

SAMPLE#	BX82100302	BX82100303	BX82100401	BX82100402	BX82100501	BX82100502	BX82100503	BX82100504
DESCR (PT.	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE
TRAVERSE#	10	10	10	10	10	10	10	10
ALONG. POS.	330	330	330	330	330	330	330	330
ACROSS POS.	52.50	52.50	52.50	52.50	52.50	52.50	52.50	52.50
THICKNESS	186.56	186.56	186.56	186.56	186.56	186.56	186.56	186.56
M (NORM)	1061	0	917	924	678	883		
DEC. (PAL.)	300.9		305.6	310.6	310.8	341.9		
INC. (PAL.)	70.5		79.4	60.8	64.2	68.9		
MEAN K	27278	24083	24705	20767	22097	25360	24419	24005
DEC. (K1)	204.4	39.9	92.1	66.5	97.1	92.1	106.5	202.6
INC. (K1)	23.3	11.8	31.2	2.0	28.0	26.9	22.6	12.4
DEC. (K2)	95.6	133.7	193.6	159.0	195.6	199.9	208.5	110.3
INC. (K2)	36.7	17.6	18.2	51.2	15.6	31.0	18.3	10.1
DEC. (K3)	319.2	277.8	309.3	334.9	311.4	329.5	329.9	342.1
INC. (K3)	44.2	68.6	52.8	38.7	57.3	46.7	60.2	73.9
NORM. K1	1.0120	1.0147	1.0121	1.0187	1.0201	1.0137	1.0124	1.0220
NORM. K2	1.0108	1.0096	1.0090	1.0069	1.0068	1.0119	1.0106	1.0082
NORM. K3	0.9773	0.9758	0.9789	0.9744	0.9731	0.9744	0.9770	0.9698

(Continued on next page)

SAMPLE#
DESCR (PT.
TRAVERSE#
ALONG. POS.
ACROSS POS.
THICKNESS
M (NORM)
DEC. (PAL.)
INC. (PAL.)
MEAN K
DEC. (K1)
INC. (K1)
DEC. (K2)
INC. (K2)
DEC. (K3)
INC. (K3)
NORM. K1
NORM. K2
NORM. K3

Table A9.1

SAMPLE#	RE82010928	RE8201093A	RE82011011	RE8201103A	RE8201104A	RE82010711	RE82010712	RE8201073A	RE8201073B	RE82010811	RE82010812	RE82010911	RE8201091B
DESCRPT.	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE
TRAVERSE#	11	11	11	11	11	11	11	11	11	11	11	11	11
ALONG. POS.	337	337	337	337	337	337	337	337	337	337	337	337	337
ACROSS. POS.	32.75	32.75	32.75	32.75	32.75	32.75	32.75	32.75	32.75	32.75	32.75	32.75	32.75
THICKNESS	160.50	160.50	160.50	160.50	160.50	160.50	160.50	160.50	160.50	160.50	160.50	160.50	160.50
M(NRM)	2728	1702				21	41			30	96	772	---
DEC.(PAL.)	256.0	UNSTABLE				UNSTABLE	336.2			299.9	302.7	345.6	310.3
INC.(PAL.)	-17.9						73.1			77.0	72.3	69.6	70.1
MEAN K	20250	15213	17138	19848		1567	2463.5		1241.3	2410.3	2512.3	19925	
DEC.(K1)	62.2	65.9	72.5	81.9		119.5	145.5		239.4	298.7	252.0	222.3	
INC.(K1)	47.4	10.2	42.6	62.8		11.3	22.1		13.3	18.8	14.2	9.5	
DEC.(K2)	237.4	151.8	214.5	206.8		221.7	55.0		118.2	204.6	143.1	5.3	
INC.(K2)	42.5	56.8	40.6	16.4		46.6	1.2		65.5	12.1	4.2	78.1	
DEC.(K3)	329.6	309.6	322.8	363.3		19.4	322.1		334.4	83.5	89.3	131.1	
INC.(K3)	2.4	31.2	20.1	21.1		41.2	67.9		20.2	67.4	75.1	7.0	
NORM. K1	1.0131	1.0142	1.0138	1.0135		1.0053	1.0052		1.0018	1.0067	1.0030	1.0112	
NORM. K2	0.9974	1.0032	1.0008	1.0012		1.0002	0.9998		1.0004	1.0020	1.0008	1.0012	
NORM. K3	0.9895	0.9856	0.9834	0.9853		0.9945	0.9950		0.9978	0.9913	0.9962	0.9875	

SAMPLE#	RE82010928	RE8201093A	RE82011011	RE8201103A	RE8201104A
DESCRPT.	DYKE	DYKE	DYKE	DYKE	DYKE
TRAVERSE#	11	11	11	11	11
ALONG. POS.	337	337	337	337	337
ACROSS. POS.	32.75	32.75	32.75	32.75	32.75
THICKNESS	160.50	160.50	160.50	160.50	160.50
M(NRM)	962	858	850		581
DEC.(PAL.)	316.4	348.1	332.2		344.7
INC.(PAL.)	64.2	67.0	73.8		81.6
MEAN K	20333	18356	15479	18326	12516
DEC.(K1)	212.6	214.7	36.2	39.4	197.3
INC.(K1)	53.5	56.4	2.6	1.9	59.7
DEC.(K2)	43.4	43.6	130.4	136.1	45.1
INC.(K2)	36.0	33.2	58.3	74.7	27.3
DEC.(K3)	309.6	310.9	304.6	308.9	308.7
INC.(K3)	5.2	4.1	31.5	15.2	12.0
NORM. K1	1.0101	1.0106	1.0108	1.0101	1.0069
NORM. K2	1.0021	1.0012	0.9993	0.9990	1.0040
NORM. K3	0.9876	0.9882	0.9899	0.9909	0.9892

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Table A9.1

SAMPLE#	DX8633010S01	DX8633010S02	DX8633010S03	DX8633010A01	DX8633010A02	DX8633010A03	DX8633010J01	DX8633010J02	DX8633010J03	DX86330201	DX86330202	DX86330203
DESCRIFT.	DX8633010S01	DX8633010S02	DX8633010S03	DX8633010A01	DX8633010A02	DX8633010A03	DX8633010J01	DX8633010J02	DX8633010J03	DX86330201	DX86330202	DX86330203
TRAVERS#	12	12	12	12	12	12	12	12	12	12	12	12
ALONG. POS.	416	416	416	416	416	416	416	416	416	416	416	416
CROSS POS.	7-85	7-85	7-85	7-75	7-85	7-75	7-75	7-75	7-55	7-55	7-55	7-55
THICKNESS	185.00	185.00	185.00	185.00	185.00	185.00	185.00	185.00	185.00	185.00	185.00	185.00
M (MM)	1725	1405	2684	2684	1318	1318	1561	1625	1625	902	1295	1295
DEC. (PAL.)	317.9	288.6	275.0	275.0	86.0	86.0	275.5	303.0	275.5	287.9	310.2	310.2
INC. (PAL.)	73.1	72.9	66.3	66.3	283.1	283.1	83.0	76.7	76.7	77.3	72.3	72.3
MEAN K	37749	32107	36111	36111	37296	36111	37563	36858	36858	23104	23104	23104
DEC. (K)	222.2	69.6	248.8	248.8	49.3	49.3	259.3	289.9	233.5	52.7	63.6	75.0
INC. (K)	14.4	6.3	10.2	10.2	5.3	5.3	29.1	64.9	38.6	57.7	42.5	37.5
DEC. (R)	111.7	168.5	339.9	339.9	157.7	157.7	123.9	50.4	83.0	230.4	203.6	244.7
INC. (R)	53.8	54.6	41.6	6.2	73.7	55.1	52.0	13.4	47.5	32.3	39.9	52.0
DEC. (R)	321.6	335.3	328.2	100.6	317.9	433.4	2.4	145.6	335.9	321.1	312.6	341.1
INC. (R)	32.4	34.7	78.0	78.0	15.4	13.2	22.2	20.8	15.1	21.3	5.0	5.0
MOHM. K1	1.0200	1.0191	1.0146	1.0108	1.0146	1.0146	1.0192	1.0082	1.0157	1.0141	1.0190	1.0200
MOHM. K2	0.9982	0.9982	1.0025	1.0025	1.0019	1.0019	1.0036	1.0016	1.0062	1.0068	1.0003	0.9957
MOHM. K3	0.9818	0.9842	0.9867	0.9867	0.9805	0.9805	0.9771	0.9901	0.9782	0.9799	0.9807	0.9822

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Table A9.1

SAMPLE#	RE84180911	RE84180912	RE84180711	RE84180721	RE82071011	RE82071012	RE82071221	RE82071231	RE82071311	RE82071312	RE84180411	RE84180412	RE84180413	RE84180311
DESCRPT.	SAT.DYKE	SAT.DYKE	SAT.DYKE	SAT.DYKE	SAT.DYKE	SAT.DYKE	SAT.DYKE	SAT.DYKE	SAT.DYKE	SAT.DYKE	SAT.DYKE	SAT.DYKE	SAT.DYKE	DYKE
TRAVERSE#	14	14	14	14	14	14	14	14	14	14	14	14	14	14
ALONG POS.	427	427	427	427	427	427	427	427	427	427	427	427	427	427
ACROSS POS.	-153.30	-153.30	-153.00	-153.00	-152.00	-152.00	-152.00	-152.00	-152.00	-152.00	-95.75	-95.75	-95.75	-78.65
THICKNESS	220.00	220.00	220.00	220.00	220.00	220.00	220.00	220.00	220.00	220.00	220.00	220.00	220.00	220.00
MEAN K	1434	1883	3222	2808	27807	30333	5262	3541	4473	4671	3114	3114	3114	3227
DEC. (PAL.)	292.2	289.9	314.9	325.7	244.7	212.1	283.8	268.2	304.6	303.8	324.7	324.7	324.7	289.1
INC. (PAL.)	61.9	63.6	71.8	67.2	56.1	56.2	75.2	64.1	78.6	75.5	56.9	56.9	56.9	73.0
MEAN K	24166	25632	40010	40330	34010	34690	45631	39260	32800	32434	30795	30795	30795	36881
DEC. (K1)	0.3	358.9	163.9	168.8	348.1	170.3	50.4	60.1	338.0	324.5	31.6	31.6	31.6	23.4
INC. (K1)	12.9	8.8	0.9	4.4	1.6	1.2	67.9	71.0	44.1	34.1	47.2	47.2	47.2	53.6
DEC. (K2)	175.2	136.4	68.2	356.0	78.7	79.7	220.4	205.0	94.6	73.3	1.0101	1.0101	1.0101	1.0091
INC. (K2)	77.1	78.1	80.8	85.6	19.3	28.4	21.8	15.7	24.8	25.4	1.0022	1.0022	1.0022	1.0004
DEC. (K3)	270.0	267.7	254.0	258.8	253.6	262.5	311.8	298.0	204.0	191.7	0.9877	0.9877	0.9877	0.9905
NORM. K1	1.0252	1.0261	1.0213	1.0193	1.0107	1.0106	1.0214	1.0308	1.0132	1.0117	0.9870	0.9870	0.9870	0.9904
NORM. K2	0.9943	0.9948	0.9991	1.0001	0.9971	0.9971	1.0003	1.0064	0.9981	0.9913	0.9877	0.9877	0.9877	0.9905
NORM. K3	0.9805	0.9791	0.9796	0.9806	0.9922	0.9923	0.9784	0.9628	0.9886	0.9913	0.9877	0.9877	0.9877	0.9905

SAMPLE#	RE84180911	RE84180912	RE82071111	RE82071121	RE84180611	RE84180612	RE84180511	RE84180312	RE84180411	RE84180412	RE84180413	RE84180311
DESCRPT.	HOSTROCK	HOSTROCK	SAT.DYKE	SAT.DYKE	HOSTROCK	HOSTROCK	HOSTROCK	HOSTROCK	DYKE	DYKE	DYKE	DYKE
TRAVERSE#	14	14	14	14	14	14	14	14	14	14	14	14
ALONG POS.	427	427	427	427	427	427	427	427	427	427	427	427
ACROSS POS.	-151.50	-151.50	-150.00	-150.00	-138.20	-138.20	-114.00	-114.00	-95.75	-95.75	-95.75	-78.65
THICKNESS	220.00	220.00	220.00	220.00	220.00	220.00	220.00	220.00	220.00	220.00	220.00	220.00
MEAN K	761	606	6773	7401	11480	10387	442	719	306.1	3208	3114	3227
DEC. (PAL.)	328.1	13.5	293.6	291.6	3.7	357.5	298.0	345.6	306.1	306.1	324.7	289.1
INC. (PAL.)	74.9	70.1	-47.8	-39.0	-18.8	-28.3	66.7	60.9	68.6	68.6	56.9	73.0
MEAN K	28534	28534	32199	32199	177.0	177.0	248.2	248.2	30921	30921	22400	36881
DEC. (K1)	187.4	187.4	177.0	177.0	177.0	177.0	248.2	248.2	30921	30921	22400	36881
INC. (K1)	36.2	36.2	27.6	27.6	27.6	27.6	248.2	248.2	30921	30921	22400	36881
DEC. (K2)	66.9	66.9	67.7	67.7	67.7	67.7	248.2	248.2	30921	30921	22400	36881
INC. (K2)	34.8	34.8	32.3	32.3	32.3	32.3	248.2	248.2	30921	30921	22400	36881
DEC. (K3)	308.0	308.0	298.6	298.6	298.6	298.6	346.6	346.6	346.6	346.6	326.7	349.3
INC. (K3)	34.8	34.8	45.0	45.0	45.0	45.0	346.6	346.6	346.6	346.6	326.7	349.3
NORM. K1	1.0037	1.0037	1.0038	1.0038	1.0038	1.0038	1.0102	1.0102	1.0102	1.0102	1.0136	1.0149
NORM. K2	1.0007	1.0007	0.9999	0.9999	0.9999	0.9999	1.0025	1.0025	1.0025	1.0025	0.9989	1.0061
NORM. K3	0.9956	0.9956	0.9956	0.9956	0.9956	0.9956	0.9873	0.9873	0.9873	0.9873	0.9875	0.9791

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Table A9.1

SAMPLE#	RE8418112	RE8418113	RE8418121	RE8418122	RE8418123	RE8418161	RE8418162	RE8418171	RE8418172	RE8418182
DESCRPT.	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE
TRAVSE#	14	14	14	14	14	14	14	14	14	14
ALONG. POS.	427	427	427	427	427	427	427	427	427	427
ACROSS POS.	-78.65	-78.65	-63.00	-63.00	-63.00	-21.50	-21.50	6.00	6.00	15.50
THICKNESS	220.00	220.00	220.00	220.00	220.00	220.00	220.00	220.00	220.00	220.00
M(NRM)	2387	2387	2499	2499	2330	478	414	75	12379	2375
DEC. (PAL.)	284.1	284.1	295.6	295.6	313.1	319.3	330.2	281.7	285.2	313.5
INC. (PAL.)	74.8	74.8	70.0	70.0	65.8	77.3	66.2	35.0	39.3	64.6
MEAN K	36820	44570	47450	43488	67183	18481	18523	410.4	506.1	19455
DEC. (K1)	82.6	182.6	165.3	75.1	203.5	138.5	141.1	99.6	259.2	261.6
INC. (K1)	29.9	70.3	61.8	2.0	58.2	21.8	21.6	61.6	67.5	16.1
DEC. (K2)	234.1	67.0	260.6	169.7	84.3	45.7	48.7	213.3	68.3	83.2
INC. (K2)	56.8	8.8	2.8	66.1	18.8	7.0	6.2	12.3	41.9	15.4
DEC. (K3)	345.0	334.2	352.1	344.2	345.8	299.0	303.6	163.2	163.2	35.7
INC. (K3)	13.1	17.5	28.0	23.8	26.1	67.0	67.5	1.7	35.7	67.5
NORM. K1	1.0259	1.0161	1.0097	1.0093	1.0110	1.0146	1.0143	1.0023	1.0042	1.0109
NORM. K2	1.0038	1.0129	1.0051	1.0058	1.0027	0.9974	0.9969	1.0000	0.9989	1.0022
NORM. K3	0.9703	0.9709	0.9852	0.9849	0.9863	0.9880	0.9888	0.9772	0.9969	0.9887

SAMPLE#	RE8418111	RE8418112	RE8418221	RE8418222	RE82070511	RE8207051B	RE8207051C	RE8207051D
DESCRPT.	DYKE	DYKE	DYKE	DYKE	CHILL.MAR.	CHILL.MAR.	CHILL.MAR.	CHILL.MAR.
TRAVSE#	14	14	14	14	14	14	14	14
ALONG. POS.	427	427	427	427	427	427	427	427
ACROSS POS.	15.50	25.00	91.85	91.85	110.00	110.00	110.00	110.00
THICKNESS	220.00	220.00	220.00	220.00	220.00	220.00	220.00	220.00
M(NRM)	2308	18	2259	2047	1138	1473	1473	
DEC. (PAL.)	279.5	304.8	303.2	288.5	288.8	290.5	286.2	48150
INC. (PAL.)	74.8	82.2	73.0	71.5	65.3	61.9	65.8	64.5
MEAN K	18766	430.2	467.4	26198	31450	34294	34294	84.1
DEC. (K1)	206.3	238.3	195.5	154.8	19.0	317.8	317.8	261.7
INC. (K1)	3.6	19.7	11.6	30.7	66.8	77.6	77.6	5.6
DEC. (K2)	112.7	126.2	337.1	262.2	259.4	269.8	86.6	171.5
INC. (K2)	44.8	46.1	75.3	22.9	8.0	7.9	7.9	1.7
DEC. (K3)	299.9	344.0	103.7	333.7	19.7	176.6	177.9	1.0164
INC. (K3)	45.0	37.0	8.9	50.0	21.7	21.7	9.6	1.0152
NORM. K1	1.0174	1.0035	1.0056	1.0139	1.0090	1.0090	1.0115	0.9864
NORM. K2	1.0029	1.0009	0.9986	0.9955	1.0022	1.0022	1.0048	
NORM. K3	0.9796	0.9956	0.9957	0.9968	0.9869	0.9869	0.9817	

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Table A9.1

SAMPLE#	REB20R1311	REB20R1312	REB20R1311	REB20R1321	REB20R132A	REB20R133A	REB20R1611	REB20R1612
DESCRPT.	CHIL.MAR.	CHIL.MAR.	CHIL.MAR.	CHIL.MAR.	CHIL.MAR.	CHIL.MAR.	CHIL.MAR.	CHIL.MAR.
TRAVERSE#	15	15	15	15	15	15	15	15
ALONG. POS.	614	614	614	614	614	614	614	614
ACROSS POS.	-74.00	-74.00	-74.00	-74.00	-74.00	-74.00	-74.00	-74.00
THICKNESS	148.00	148.00	148.00	148.00	148.00	148.00	148.00	148.00
PA (NRH)	912	887	975	1184	1646	2208	1194	1075
DEC. (PAL.)	277.8	282.6	281.3	275.3	274.6	286.5	287.5	266.7
INC. (PAL.)	52.3	54.6	54.2	49.8	46.4	57.5	45.6	46.7
MEAN K	26996	26357	24275	25045	29916	29036	29876	26247
DEC. (K1)	96.4	96.4	90.9	90.7	95.1	102.7	108.6	102.2
INC. (K1)	10.5	12.4	12.2	15.2	8.6	56.6	13.6	14.8
DEC. (K2)	292.4	285.1	271.9	283.1	234.4	266.8	273.9	258.5
INC. (K2)	79.1	77.4	77.8	74.5	78.7	32.4	75.9	73.8
DEC. (K3)	187.0	186.8	180.9	181.6	4.0	1.5	17.8	10.6
INC. (K3)	2.9	1.8	0.2	3.2	7.3	7.4	3.4	6.2
NORM. K1	1.0202	1.0228	1.0111	1.0120	1.0169	1.0143	1.0094	1.0096
NORM. K2	1.0049	1.0046	1.0065	1.0058	0.9993	1.0032	0.9989	1.0025
NORM. K3	0.9749	0.9726	0.9824	0.9822	0.9838	0.9825	0.9917	0.9979

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SAMPLE#
DESCRPT.
TRAVERSE#
ALONG. POS.
ACROSS POS.
THICKNESS
PA (NRH)
DEC. (PAL.)
INC. (PAL.)
MEAN K
DEC. (K1)
INC. (K1)
DEC. (K2)
INC. (K2)
DEC. (K3)
INC. (K3)
NORM. K1
NORM. K2
NORM. K3

APPENDIX 10: PALEOMAGNETIC AND AMS DATA: SAMPLE AND SITE MEANS

A10.1 INTRODUCTION

Palcomagnetic sample means are given in Table A10.1 and displayed in Fig. 9.5. Palcomagnetic site means are given in Tables 9.1 and 9.2 and displayed in Figs. 9.6 and 9.8.

AMS sample means are given in Table A10.2 and displayed in Fig. 8.7. AMS site means are given in Table 8.1 and displayed in Fig. 8.8.

A10.2 EXPLANATION OF TABLE A10.1

Palcomagnetic vectors, DEC.(PAL.), INC.(PAL.) have been averaged following the approach of Fisher (1953). $M(NRM)$ was computed by an arithmetic average. Palcomagnetic directions were calculated for a common location of longitude $81.4^{\circ}W$ and latitude $48.5^{\circ}N$.

The sample labelled RE8204161 corresponds to geochemical sample RE820416B.

Table A10.1

SAMPLE#	RE842803	RE842804	RE842801	RE842802	RE842805	RE842811	RE842810	RE842815	RE842812	RE842813	RE842511	RE842510
DESCRIPT.	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	SAT. DYKE	SAT. DYKE	SAT. DYKE	HOSTROCK	DYKE
TRAVERSE#	2	2	2	2	2	2	2	2	2	2	3	3
ALONG. POS.	167	167	167	167	167	167	167	167	167	167	201	201
ACROSS POS.	-25.30	-20.75	-14.10	-8.75	-0.10	43.55	43.75	50.25	52.95	53.75	-78.25	-72.00
THICKNESS	88.50	88.50	88.50	88.50	88.50	88.50	88.50	88.50	88.50	88.50	148.50	148.50
M (NRH)	1439	28972	1916	946	2195	1558	11524	1266	4289	1517	321	1077
DEC. (PAL.)	267.8	253.5	271.5	283.5	280.9			276.2	271.3	306.0	295.9	274.2
INC. (PAL.)	63.0	65.4	65.3	63.2	65.5			63.2	54.9	72.0	56.6	58.9

SAMPLE#	RE842509	RE842507	RE842506	RE842505	RE842504	RE842503	RE842502	RE842501	RE842403	RE842404	RE842405	RE842402
DESCRIPT.	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE
TRAVERSE#	3	3	3	3	3	3	3	3	4	4	4	4
ALONG. POS.	201	201	201	201	201	201	201	201	206	206	206	206
ACROSS POS.	-57.00	-27.50	-16.50	25.50	29.75	39.25	54.50	56.65	-54.45	-54.45	-41.75	-37.75
THICKNESS	148.50	148.50	148.50	148.50	148.50	148.50	148.50	148.50	137.50	137.50	137.50	137.50
M (NRH)	1229	994	981	845	1248	538	701	264	1001	1428	1103	1033
DEC. (PAL.)	304.6	295.1	303.5	290.4	284.9	292.3	289.3	303.9	284.2	286.6	279.0	280.4
INC. (PAL.)	59.9	49.8	46.9	45.7	45.9	44.3	48.9	70.6	53.5	54.7	52.9	44.2

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Table A10.1

SAMPLE#	RE842401	RE8204161	RE8204162	RE820417	RE820418	RE820419	RE820420	RE820421	RE820308	RE820309	RE820310	RE820306
DESCR' T.	DYKE	DYKELET	DYKE	SAT. DYKE	SAT. DYKE	SAT. DYKE	SAT. DYKE	SAT. DYKE	HUSTROCK	HUSTROCK	HUSTROCK	HUSTROCK
TRAVERSE#	4	4	4	4	4	4	4	4	5	5	5	5
ALONG. POS.	206	206	206	206	206	206	206	206	216	216	216	216
ACROSS POS.	-26.75	-12.25	-12.25	68.75	68.75	68.75	68.75	68.75	-295.00	-295.00	-295.00	-84.70
THICKNESS	137.50	137.50	137.50	137.50	137.50	137.50	137.50	137.50	109.00	109.00	109.00	109.00
M (NRH)	1426	3442	4911	3661	1855	2769	316	1332	1104	489	168782	740
DEC. (PAL.)	301.5	288.3	271.4	291.7	311.5	288.7	287.2	291.7	219.4	212.8	225.8	293.4
INC. (PAL.)	60.5	63.3	64.3	47.0	52.0	61.3	61.0	65.0	-12.4	-9.7	-28.4	61.3

SAMPLE#	RE820307	RE820305	RE820302	RE820301	RE840151	RE840150	RE840149	RE840148	RE840152	RE840147	RE840125	RE840126
DESCR' T.	HUSTROCK	SAT. DYKE	HUSTROCK	HUSTROCK	HUSTROCK	HUSTROCK	HUSTROCK	HUSTROCK	HUSTROCK	CHIL. MAR.	DYKE	DYKE
TRAVERSE#	5	5	5	5	7	7	7	7	7	7	7	7
ALONG. POS.	216	216	216	216	243	243	243	243	243	243	243	243
ACROSS POS.	-84.70	-76.70	-68.70	-63.50	-137.75	-133.50	-117.25	-108.40	-104.75	-104.75	-101.45	-92.35
THICKNESS	109.00	109.00	109.00	109.00	209.50	209.50	209.50	209.50	209.50	209.50	209.50	209.50
M (NRH)	1110	647	1067	562	75	36	102	1	314	1194	460	4426
DEC. (PAL.)	306.1	311.2	312.3	328.7	342.1	154.0	266.6	302.2	286.7	332.0	306.1	297.1
INC. (PAL.)	68.3	63.5	68.9	64.0	77.1	74.3	64.9	64.4	69.6	54.7	68.1	83.6

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Table A10.1

SAMPLE#	RE840130	RE840127	RE840128	RE840129	RE840145	RE840131	RE840132	RE840133	RE840134	RE840135	RE840136	RE840137
DESCRPT.	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE
TRAVERSE#	7	7	7	7	7	7	7	7	7	7	7	7
A LONG. POS.	243	243	243	243	243	243	243	243	243	243	243	243
ACROSS POS.	-75.35	-60.25	-49.75	-40.55	-32.95	-20.60	-13.35	-1.25	11.50	25.05	38.95	62.25
THICKNESS	209.50	209.50	209.50	209.50	209.50	209.50	209.50	209.50	209.50	209.50	209.50	209.50
M (NRM)	1968	1329	1268	1439	2041	1866	2032	2115	1854	2443	1897	2180
DEC. (PAL.)	303.5	295.5	299.3	296.2	298.6	288.2	281.7	282.6	300.9	278.9	282.2	291.0
INC. (PAL.)	78.0	68.7	66.6	64.2	70.4	71.0	68.2	73.0	72.8	72.5	67.1	71.1

SAMPLE#	RE840138	RE840140	RE840142	RE840143	RE840105	RE840107	RE840103	RE840102	RE840101	RE840101	RE840102	RE840103
DESCRPT.	DYKE	DYKE	DYKE	SAT. DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE
TRAVERSE#	7	7	7	7	7	7	7	7	7	7	7	7
A LONG. POS.	243	243	243	243	265	265	265	265	265	265	265	265
ACROSS POS.	75.75	90.60	98.85	114.45	-15.00	-14.00	-9.00	-4.00	0.00	0.00	0.00	0.00
THICKNESS	209.50	209.50	209.50	209.50	231.00	231.00	231.00	231.00	231.00	231.00	231.00	231.00
M (NRM)	1381	2174	1783	3037	1003	1010	1229	1492	861	849	332	1301
DEC. (PAL.)	283.9	321.9	291.5	270.5	309.2	293.6	295.9	296.7	297.4	274.4	266.6	300.5
INC. (PAL.)	73.7	63.2	70.6	72.6	61.4	67.4	64.9	66.6	64.2	73.5	71.7	70.7

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Table A10.1

SAMPLE#	BX821704	BX821705	BX821601	BX821602	BX821603	BX821604	BX821605	BX821301	BX821302	BX821303	BX821304	BX820201
DESCRIPT.	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	HOSTROCK	HOS. ROCK	HOSTROCK	HOSTROCK	HOSTROCK
TRAVERSE#	9	9	9	9	9	9	9	10	10	10	10	10
ALONG. POS.	320	320	320	320	320	320	320	30	330	330	330	330
ACROSS POS.	-89.00	-89.00	0.00	0.00	0.00	0.00	0.00	-102.00	-102.00	-102.00	-102.00	-93.29
THICKNESS	186.00	186.00	186.00	186.00	186.00	186.00	186.00	186.56	186.56	186.56	186.56	186.56
M (NRH)	1073	690	691	706	776	506	685	854	692	854	81	81
DEC. (PAL.)	219.7	270.6	292.4	291.7	300.3	296.6	277.1	312.3	294.9	300.1	302.2	339.0
INC. (PAL.)	80.7	76.9	61.5	65.2	67.0	55.8	65.9	76.7	73.3	76.1	77.7	73.9

SAMPLE#	RE820203	RE820204	RE820206	RE820207	RE820209	RE821201	RE821202	RE821203	RE821204	RE821101	RE821102	RE821103
DESCRIPT.	HYBRID	HYBRID	HYBRID	HYBRID	HYBRID	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE
TRAVERSE#	10	10	10	10	10	10	10	10	10	10	10	10
ALONG. POS.	330	330	330	330	330	330	330	330	330	330	330	330
ACROSS POS.	-93.28	-93.28	-93.28	-93.28	-93.28	-82.58	-82.58	-92.58	-82.58	-6.73	-6.73	-6.73
THICKNESS	186.56	186.56	186.56	86.56	186.56	186.56	186.56	186.56	186.56	186.56	186.56	186.56
M (NRH)	660	310	126	965	23	2358	1254	1191	992	439	515	397
DEC. (PAL.)	12.4	---	341.2	313.3	301.1	318.7	314.7	305.5	308.9	291.3	320.0	316.3
INC. (PAL.)	80.4	---	69.6	73.8	63.2	77.2	79.4	75.2	75.0	71.2	72.7	67.0

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Table A10.1

SAMPLE#	BX821001	BX821002	BX821003	BX821004	BX821005	BX821401	BX821402	BX821403	BX821404	BX821501	BX821502
DESCRIPT.	DYKE	DYKE	DYKE	DYKE	DYKE	HOSTROCK	HOSTROCK	HOSTROCK	HOSTROCK	HOSTROCK	HOSTROCK
TRAVERSE#	10	10	10	10	10	10'	10'	10'	10'	10'	10'
ALONG POS.	330	330	330	330	330	331	331	331	331	331	331
ACROSS POS.	-6.73	52.50	52.50	52.50	52.50	119.00	119.00	119.00	119.00	443.70	443.70
THICKNESS	186.56	186.56	186.56	186.56	186.56	143.00	143.00	143.00	143.00	143.00	143.00
M (NRM)	509	611	895	921	781						
DEC. (PAL.)	312.7	321.5	329.1	309.1	324.8	296.7	289.0	295.3	299.7	222.0	208.0
INC. (PAL.)	73.0	77.4	68.4	70.4	67.5	77.0	75.6	75.6	75.0	-7.1	-10.7

SAMPLE#	BX821503	BX821504	BX820106	BX820107	BX820108	BX820109	BX820110	BX863304	BX863303	BX863302	BX863301
DESCRIPT.	HOSTROCK	HOSTROCK	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE
TRAVERSE#	10'	10'	11	11	11	11	11	12	12	12	12
ALONG POS.	331	331	337	337	337	337	337	416	416	416	416
ACROSS POS.	443.70	443.70	32.75	32.75	32.75	32.75	32.75	7-75	-65.00	7-55	7-50
THICKNESS	143.00	143.00	160.50	160.50	160.50	160.50	160.50	185.00	185.00	185.00	185.00
M (NRM)			72	72	864	864	716	2001	1594	1098	1878
DEC. (PAL.)	209.8	209.5	255.3	336.5	301.5	330.0	340.1	277.1	295.1	301.3	318.5
INC. (PAL.)	-8.2	-8.0	-16.8	73.2	75.0	68.7	67.9	75.5	80.7	75.6	71.3

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Table A10.1

SAMPLE#	RE841808	RE841807	RE820710	RE820712	RE820713	RE841810	RE841809	RE820711	RE841806	RE841805	RE841804	RE841803
DESCRPT.	SAT.DYKE	SAT.DYKE	SAT.DYKE	SAT.DYKE	SAT.DYKE	SAT.DYKE	HOSTROCK	SAT.DYKE	HOSTROCK	HOSTROCK	DYKE	DYKE
TRAVERSE#	14	14	14	14	14	14	14	14	14	14	14	14
ALONG. POS.	427	427	427	427	427	427	427	427	427	427	427	427
ACROSS POS.	-153.30	-153.00	-152.00	-152.00	-152.00	-151.80	-151.50	-150.00	-138.20	-114.00	-95.75	-78.65
THICKNESS	220.00	220.00	220.00	220.00	220.00	220.00	220.00	220.00	220.00	220.00	220.00	220.00
M (NRM)	1659	3016	29069	4402	4573	4310	684	7086	10934	581	3161	2307
DEC. (PAL.)	290.5	321.1	228.9	273.2	305.1	272.0	354.9	290.6	359.1	324.4	317.0	286.6
INC. (PAL.)	64.6	69.9	58.1	70.7	77.6	71.8	73.6	-42.0	-5.5	66.0	63.5	74.6

SAMPLE#	RE841802	RE841816	RE841801	RE841817	RE841818	RE841811	RE841822	RE820705	RE820813	RE820814	RE820815	RE820816
DESCRPT.	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE	CHIL.MAR.	CHIL.MAR.	CHIL.MAR.	CHIL.MAR.	CHIL.MAR.
TRAVERSE#	14	14	14	14	14	14	14	14	15	15	15	15
ALONG. POS.	427	427	427	427	427	427	427	427	614	614	614	614
ACROSS POS.	-63.00	-21.50	1.50	6.00	15.50	25.00	91.85	110.00	-74.00	-74.00	-74.00	-74.00
THICKNESS	220.00	220.00	220.00	220.00	220.00	220.00	220.00	220.00	148.00	148.00	148.00	148.00
M (NRM)	2414	446	69	14066	2441	13	2154	1306	900	1080	1927	1135
DEC. (PAL.)	305.1	326.9	282.2	318.0	300.7	298.6	295.5	288.0	277.9	275.9	277.6	264.3
INC. (PAL.)	68.7	72.1	38.4	68.1	71.1	73.2	73.0	65.2	56.1	54.8	54.8	49.6

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Table A10.1

SAMPLE#	RE820910	RE820907	RE820911	RE820908	RE820909	RE820912
DESCRIPT.	DYKE	DYKE	DYKE	DYKE	DYKE	DYKE
TRAVERSE#	16	16	16	16	16	16
ALONG. POS.	702	702	702	702	702	702
ACROSS POS.	-17.80	-17.80	-13.15	-13.15	-8.50	3.70
THICKNESS	85.00	85.00	85.00	85.00	85.00	85.00
THICKNESS	1232	1346	1350	1531	1701	1602
DEC. (PAL.)	273.6	286.1	276.4	278.8	288.9	279.4
INC. (PAL.)	55.4	59.9	58.0	58.0	59.3	59.2

SAMPLE#
 DESCRIPT.
 TRAVERSE#
 ALONG. POS.
 ACROSS POS.
 THICKNESS
 THICKNESS
 DEC. (PAL.)
 INC. (PAL.)

7 of /de 7

MICRO

Table A10.2: AMS sample means calculated from specimen data (Table A9.1) using the axis-averaging technique

Sample Number	Mean Suscept.	K1		K2		K3		Scatter About Mean Direction			Angular Dispersion		
		Maximum Dec.	Axis Inc.	Intermed. Dec.	Axis Inc.	Minimum Dec.	Axis Inc.	S1	S2	S3	C1	C2	C3
RE8-2803	19490	224.2	17.4	312.3	16.2	81.2	67.0	0.95	0.82	0.77	18	35	40
RE8-2804	17813	240.4	3.2	300.4	25.2	0.1	22.5	0.73	0.60	0.64	43	53	50
RE8-2801	18459	66.4	7.0	162.3	41.5	327.7	47.4	0.99	0.98	0.99	8	11	8
RE8-2802	18619	237.4	16.2	121.9	59.2	331.6	30.0	0.87	0.84	0.94	30	33	20
RE8-2805	25596	250.2	10.3	342.1	0.9	102.4	85.1	0.91	0.81	0.88	24	36	28
RE8-2811	13913	161.1	4.2	38.0	82.3	251.5	6.3	0.98	0.99	1.00	11	8	0
RE8-2810	8851	83.5	0.8	2.7	45.1	176.1	46.3	0.98	0.53	0.52	11	58	59
RE8-2815	47630	266.7	42.2	41.8	38.1	152.4	23.7	0.97	0.97	0.99	14	14	8
RE8-2812	63040	313.0	84.4	87.5	18.8	182.9	14.5	0.95	0.92	0.97	18	23	16
RE8-2813	47830	242.8	54.4	39.5	33.5	136.0	12.9	0.84	0.84	0.99	35	33	8
RE8-2510	47800	273.9	64.7	64.4	22.4	159.1	11.2	1.00	1.00	1.00	0	0	0
RE8-2509	11520	352.2	26.2	242.4	34.9	101.1	48.9	0.65	0.61	0.96	49	52	16
RE8-2507	13666	12.6	41.3	277.6	3.2	184.5	48.3	0.78	1.00	0.78	39	0	39
RE8-2506	14788	76.6	15.2	47.5	66.0	276.3	48.5	0.68	0.58	0.74	47	55	42
RE8-2505	17910	272.6	47.5	15.1	10.5	117.4	39.8	0.69	1.00	0.69	46	0	46
RE8-2504	24611	338.4	17.8	207.8	40.3	102.7	39.1	0.65	0.71	0.62	49	45	52
RE8-2503	20292	95.4	27.1	3.0	8.0	255.4	61.1	0.87	0.99	0.87	30	8	30
RE8-2502	16976	43.7	7.4	25.3	11.7	308.2	11.4	0.56	0.45	0.69	56	63	46
RE8-2501	1557	256.8	41.9	80.7	51.2	349.9	4.1	0.69	0.99	0.69	46	8	46
RE8-2403	15304	302.0	35.0	210.1	2.6	121.6	54.9	0.82	0.94	0.89	35	20	27
RE8-2404	17565	280.5	30.1	173.0	33.3	41.9	45.8	0.98	0.76	0.75	11	41	41
RE8-2405	20629	132.9	1.3	223.3	16.0	45.3	75.5	0.68	0.68	1.00	47	47	0
RE8-2402	21645	251.3	11.1	160.6	0.8	69.3	78.4	0.96	0.98	0.98	11	11	11
RE8-2401	17726	285.5	22.4	179.8	35.3	43.0	45.4	0.99	0.92	0.93	8	23	22
RE8-204162	27171	255.3	1.8	165.5	5.9	1.7	84.0	0.98	0.98	0.99	11	11	8
RE8-204161	23588	266.1	58.8	83.7	31.0	175.1	2.2	0.84	0.84	1.00	33	33	0
RE8-20419	68933	74.4	20.2	309.3	58.6	170.8	26.0	0.99	0.62	0.62	8	52	52
RE8-20420	39353	172.3	6.0	81.0	10.8	286.8	76.7	0.92	0.93	0.99	23	55	8
RE8-20421	46175	303.0	51.2	68.5	24.8	172.6	27.8	1.00	0.99	0.99	0	8	8
RE8-20305	18816	351.5	12.5	243.6	54.8	90.0	32.2	1.00	0.91	0.91	0	24	24
RE8-0125	10761	3.4	1.0	93.8	7.1	276.1	82.7	0.98	0.95	0.97	31	18	16
RE8-0126	8107	51.5	1.6	233.4	45.9	128.6	41.3	0.61	0.49	0.66	52	61	49
RE8-0130	35740	88.9	44.7	195.8	13.4	294.7	39.9	0.96	0.93	0.93	20	22	22
RE8-0127	25963	76.5	28.0	222.2	56.4	339.0	15.9	0.98	0.96	0.97	11	16	16
RE8-0129	21194	246.0	12.7	141.7	21.2	9.5	48.7	0.91	0.66	0.66	24	49	49
RE8-0122	28960	69.8	0.8	337.8	70.2	158.8	20.1	0.96	0.96	0.98	16	16	11
RE8-0145	28020	68.8	2.2	335.1	65.5	159.6	24.0	0.98	0.94	0.95	11	20	18
RE8-0131	35710	71.7	35.2	220.0	50.4	330.1	15.8	1.00	1.00	1.00	0	0	0
RE8-0132	30490	79.0	15.4	257.9	74.7	349.9	0.6	0.99	0.99	0.97	2	16	16
RE8-0133	37829	67.1	16.6	164.6	27.9	309.1	56.6	0.99	0.92	0.92	5	23	23
RE8-0134	36399	81.1	20.1	207.4	46.5	333.7	29.1	0.99	0.98	0.99	2	11	8
RE8-0135	40376	217.7	19.9	106.3	45.8	322.9	40.3	0.76	0.76	0.99	41	41	8

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Table A10.2

Sample Number	Mean Suscept.	ϵ_1		ϵ_2		ϵ_3		Scatter About Mean Direction			Angular Dispersion	
		Maximum Dec.	Axis Inc.	Intermed. Dec.	Axis Inc.	Minimum Dec.	Axis Inc.	δ_1	δ_2	δ_3	C1	C2
R840136	34652	111.0	53.0	237.4	5.8	323.6	39.7	0.57	0.41	0.89	55	52
R840137	51990	55.9	12.5	160.2	46.9	317.1	30.0	0.92	0.93	0.98	23	22
R840138	25040	91.9	10.3	187.1	28.4	341.4	57.9	0.92	0.91	0.98	23	24
R840140	14854	158.7	0.6	265.9	6.8	44.6	82.7	0.97	0.75	0.76	14	41
R840142	22118	177.0	19.0	287.2	16.6	61.0	62.5	0.91	0.61	0.55	24	52
R861105	21265	77.5	2.9	306.3	83.3	168.4	5.9	0.94	0.90	0.93	20	26
R861104	15241	241.8	28.9	63.1	59.8	167.3	7.5	0.96	0.97	0.98	16	14
R861103	18127	259.8	11.1	163.3	34.2	4.5	54.4	0.98	0.97	0.96	11	14
R861102	21519	236.1	43.3	61.1	33.6	328.5	14.0	0.59	0.77	0.74	54	40
R861101	20758	283.4	15.6	29.9	34.1	176.5	47.5	0.84	0.97	0.81	33	14
R821701	22176	234.2	0.2	144.3	8.8	328.7	81.1	0.99	0.98	0.99	8	11
R821702	10154	192.2	5.7	327.9	80.2	98.6	9.6	0.85	0.85	0.94	32	32
R821703	20522	205.2	50.6	352.2	36.6	94.1	16.9	0.97	0.97	1.00	14	14
R821704	23962	162.0	45.4	58.8	6.9	321.4	48.0	0.60	0.62	0.96	53	52
R821705	15914	213.8	32.1	306.6	2.4	26.4	56.8	0.76	0.89	0.87	41	27
R821601	34462	131.1	52.3	12.5	17.3	287.0	31.9	0.53	0.61	0.78	58	52
R821602	35057	106.0	74.0	37.6	1.7	309.7	25.0	0.66	0.66	0.93	49	49
R821603	36309	86.6	74.2	214.3	9.8	306.7	12.2	0.96	0.96	1.00	16	16
R821604	32553	91.7	61.9	348.8	9.2	250.3	30.9	0.97	0.66	0.64	14	49
R821605	32837	106.4	62.4	1.8	10.2	261.3	25.3	0.87	0.66	0.97	48	49
R821201	27784	250.1	38.8	67.5	46.7	156.4	1.2	0.92	0.74	0.78	23	42
R821202	17048	250.1	61.8	54.0	27.1	149.2	9.4	0.83	0.81	0.98	34	36
R821203	23992	271.8	5.8	174.7	65.9	1.0	17.2	0.67	0.67	0.96	48	48
R821204	25611	54.0	0.1	163.3	88.1	322.9	1.8	0.96	0.96	0.98	11	16
R821101	16473	41.8	39.8	303.2	13.5	199.8	67.2	0.88	0.88	1.00	28	28
R821102	20557	51.4	23.8	151.1	19.6	275.5	57.8	1.00	0.62	0.62	0	52
R821103	17098	19.0	20.4	116.7	16.6	228.5	63.4	0.79	0.73	0.91	38	43
R821104	18092	57.9	3.5	324.0	36.0	155.2	53.7	0.93	0.86	0.93	22	31
R820001	23422	183.5	23.5	84.7	15.7	321.7	60.7	0.74	0.72	0.97	42	44
R820002	20273	117.3	27.0	215.3	12.6	322.5	57.5	0.91	0.88	0.93	24	28
R820003	24638	47.1	5.1	137.1	31.3	310.2	55.8	0.75	0.73	0.94	41	43
R820004	22736	78.3	17.0	180.0	35.9	323.7	46.5	0.69	0.87	0.96	27	30
R820005	23970	95.1	24.9	197.8	22.0	326.4	59.9	0.75	0.74	0.96	41	42
R820106	18112	63.3	42.8	209.2	41.7	316.6	19.2	0.87	0.82	0.94	30	35
R820107	1750	119.9	12.8	218.3	45.7	348.7	45.7	0.66	0.60	0.81	49	53
R820108	2461	275.1	17.9	183.6	4.2	85.8	71.3	0.85	0.86	1.00	32	31
R820109	19551	217.3	41.7	60.0	47.9	310.5	0.8	0.87	0.86	0.99	30	31
R820110	15440	214.8	12.3	95.5	64.4	307.5	19.5	0.76	0.75	0.98	41	41
R863305	34856	230.1	10.1	126.7	52.9	328.3	36.4	0.91	0.91	0.99	24	24
R863304	38681	236.9	12.2	11.1	84.2	154.3	9.1	0.91	0.59	0.84	24	54
R863303	35123	255.2	45.4	81.2	43.1	341.2	6.7	0.87	0.78	0.84	30	39
R863302	23352	65.2	46.2	225.3	42.5	325.1	9.2	0.97	0.94	0.94	14	20

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Table A10.2

Sample Number	Mean Suscept.	g1		g2		g3		Scatter About Mean Direction			Angular Dispersion	
		Maximum Dec.	Angle Inc.	Intermed. Dec.	Angle Inc.	Minimum Dec.	Angle Inc.	g1	g2	g3	c1	c2
BE803301	46027	254.7	10.1	13.3	62.9	148.0	15.6	0.73	0.55	0.79	43	57
BE803302	24899	359.6	10.6	156.6	78.3	268.9	4.5	1.00	0.99	1.00	0	0
BE803303	40170	146.3	2.6	46.5	84.3	256.4	4.9	1.00	0.99	0.99	0	0
BE803304	34350	349.2	0.2	79.2	23.9	258.8	66.2	1.00	0.99	0.99	0	0
BE803305	42445	54.9	69.5	212.6	18.9	304.9	7.0	1.00	0.98	0.98	0	11
BE803306	32617	330.8	39.3	84.0	25.5	198.3	40.5	0.98	0.97	0.99	11	14
BE803307	36941	368.8	27.5	93.5	25.9	219.8	50.4	0.99	1.00	0.99	0	0
BE803308	30376	182.0	32.0	67.3	33.5	303.6	40.0	0.99	1.00	0.99	0	0
BE803309	28038	251.6	6.8	154.5	60.8	344.3	32.2	0.88	0.89	0.93	28	27
BE803310	46090	68.2	31.2	224.5	49.3	342.7	19.7	0.68	0.68	0.98	47	47
BE803311	46707	200.0	57.9	85.7	14.2	347.3	26.0	0.66	0.66	1.00	49	49
BE803312	18502	139.8	21.7	47.2	6.6	301.2	67.3	1.00	1.00	1.00	0	0
BE803313	458	223.3	80.1	48.3	15.5	327.0	10.3	0.67	0.73	0.85	48	43
BE803314	9036	248.5	40.0	133.2	19.2	11.5	46.3	0.80	0.71	0.83	37	45
BE803315	19110	194.2	12.5	95.9	33.4	305.3	52.8	0.93	0.91	0.98	22	24
BE803316	458	216.5	16.8	110.8	73.8	310.3	16.1	0.87	0.77	0.65	30	40
BE803317	24237	120.0	37.2	240.4	40.0	3.8	26.1	0.76	0.91	0.80	41	24
BE803318	37964	7.4	78.7	266.0	2.0	175.3	11.0	0.97	0.98	0.98	14	11
BE803319	26675	96.4	11.5	288.4	78.3	186.9	2.4	1.00	1.00	1.00	0	0
BE803320	24666	90.8	13.7	278.2	76.2	181.3	1.7	1.00	1.00	1.00	0	0
BE803321	29684	97.8	32.6	260.8	56.2	2.7	7.3	0.83	0.83	1.00	34	34
BE803322	28061	105.4	16.5	265.7	75.0	14.2	4.8	1.00	1.00	1.00	0	0
BE803323	35288	267.1	11.0	44.1	75.0	174.6	10.2	0.97	0.97	1.00	14	14
BE803324	35938	262.9	5.3	11.7	73.0	171.7	15.3	0.94	0.95	0.98	20	18
BE803325	35951	267.7	15.3	58.7	72.4	175.2	8.6	0.97	0.97	0.99	14	14
BE803326	38658	271.2	7.7	28.9	74.1	178.4	13.2	0.95	0.95	0.99	18	18
BE803327	32905	281.9	24.6	60.2	58.8	183.0	18.6	0.96	0.96	0.97	16	16
BE803328	33372	266.6	8.7	26.1	72.8	174.3	14.6	1.00	1.00	1.00	0	0

Mean susceptibility is the bulb susceptibility per unit volume and is measured in 10⁻⁶ SI units.

$C_1 = \arccos(S_1)$ where $S_1 = \text{lean}/(\text{lean} + \text{lean})$

lean, lint and lean are the eigenvalues of the orientation tensor calculated for each set of principal axes (Schofield et al., 1988)

APPENDIX 11: BULK MASS SUSCEPTIBILITY**A11.1 EXPLANATION OF TABLE A11.1**

Mass susceptibility data are given in units of 10^{-9} (SI). Across-Dyke Position and Description can be understood with reference to Appendix 5

Table A11.1: Bulk susceptibility per unit mass.

Traverse Number	Sample Number	Across-Dyke Position (metres)	Descript.	Mass Suscept.	Unit 1 or Unit 2
1		44.25	Half-Width		
1	8427.01	-40.25	Main Dyke	6513	1
1	8427.02	-39.50	Main Dyke	8895	1
1	8427.03	-29.75	Main Dyke	4555	1
2		44.25	Half-Width		
2	8428.14	-41.30	Main Dyke	8034	1
2	8428.03	-25.30	Main Dyke	7865	1
2	8428.06	-23.25	Main Dyke	7602	1
2	8428.01	-14.10	Main Dyke	7531	1
2	8428.02	-8.75	Main Dyke	6256	1
2	8428.05	-0.95	Main Dyke	6711	1
2	8428.07	17.15	Main Dyke	7430	1
2	8428.08	25.75	Main Dyke	5493	1
2	8428.09	36.40	Main Dyke	10925	1
2	8428.11	43.55	Main Dyke	6704	1
2	8428.10	43.75	Main Dyke	2399	1
2	8428.15	50.25	Sat. Dyke	18077	1
2	8428.12	52.95	Sat. Dyke	11489	1
3		74.25	Half-Width		
3	8425.10	-72.00	Main Dyke	17470	1
3	8425.13	-57.65	Main Dyke	5741	1
3	8425.09	-57.00	Main Dyke	6941	1
3	8425.08	-51.00	Main Dyke	6095	1
3	8425.07	-27.50	Main Dyke	7004	1
3	8425.06	-16.50	Main Dyke	6365	1
3	8425.12	3.25	Main Dyke	7782	1
3	8425.05	25.50	Main Dyke	7115	1
3	8425.04	29.75	Main Dyke	7446	1
3	8425.03	39.25	Main Dyke	8217	1
3	8425.02	54.50	Main Dyke	7209	1
3	8425.01	56.65	Main Dyke	506	1
3	8425.15	61.75	Main Dyke	4931	1
4		68.75	Half-Width		
4	8204.15	-59.60	Boulder?	6568	1
4	8204.14	-54.70	Main Dyke	3781	1
4	8204.13	-38.95	Main Dyke	5990	1
4	8204.16A	-12.25	Main Dyke	9064	1
4	8204.16B	-12.25	Dykelet	9192	1
4	8204.11	-2.10	Main Dyke	6626	1
4	8204.10	15.40	Main Dyke	6890	1
4	8204.09	23.75	Main Dyke	6900	1
4	8204.08	33.25	Weathered	9563	1
4	8204.07	40.45	Dykelet	24903	1
4	8204.19	68.75	Sat. Dyke	20191	1

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Table A11.1		Across-Dyke	Mass	Unit 1
Traverse Number	Sample Number	Position (metres)	Suscept.	or Unit 2
5		54.50	Half-Width	
5	8203.05	-76.70	Sat. Dyke	6008 1
5	8203.14	-46.75	Main Dyke	7478 1
5	8203.15	-43.50	Main Dyke	5161 1
5	8203.13	-34.35	Main Dyke	4827 1
5	8203.11	-10.60	Main Dyke	12018 2
5	8203.12	-9.35	Main Dyke	11682 2
6		104.75	Half-Width	
6	8430.04	-101.00	Main Dyke	5106 1
6	8430.03	-99.35	Main Dyke	-- 1
6	8430.03	-99.35	Main Dyke	9645 1
6	8430.05	-92.75	Main Dyke	4778 1
6	8430.02	-90.35	Main Dyke	4750 1
6	8430.01	-82.75	Main Dyke	7424 1
7		104.75	Half-Width	
7	8401.51	-137.75	Hostrock	3405 Hostrock
7	8401.50	-133.50	Hostrock	517 Hostrock
7	8401.49	-117.25	Hostrock	3019 Hostrock
7	8401.48	-108.40	Hostrock	-- Hostrock
7	8401.52	-104.75	Hostrock	3372 Hostrock
7	8401.47	-104.75	Altered	39873 1
7	8401.01	-102.95	Main Dyke	5300 1
7	8401.02	-101.00	Main Dyke	6599 1
7	8401.03	-100.20	Main Dyke	6190 1
7	8401.04	-98.00	Main Dyke	6609 1
7	8401.05	-93.35	Main Dyke	5013 1
7	8401.06	-88.75	Main Dyke	11770 1
7	8401.07	-77.10	Main Dyke	17584 1
7	8401.08	-71.00	Main Dyke	10284 2
7	8401.09	-60.85	Main Dyke	10926 2
7	8401.10	-52.85	Main Dyke	10830 2
7	8401.11	-46.15	Main Dyke	10578 2
7	8401.12	-37.35	Main Dyke	9865 2
7	8401.13	-28.60	Main Dyke	9094 2
7	8401.31	-20.60	Main Dyke	10433 2
7	8401.14	-11.80	Main Dyke	9002 2
7	8401.15	-6.80	Main Dyke	9739 2
7	8401.33	-1.25	Main Dyke	12308 2
7	8401.34	11.50	Main Dyke	12548 2
7	8401.16	15.55	Main Dyke	11676 2
7	8401.17	19.80	Main Dyke	10673 2
7	8401.35	25.05	Main Dyke	12548 2
7	8401.18	25.65	Main Dyke	12101 2
7	8401.19	31.55	Main Dyke	11370 2
7	8401.20	36.75	Main Dyke	10280 2
7	8401.21	44.15	Main Dyke	11768 2
7	8401.22	63.50	Main Dyke	17264 2
7	8401.23	69.85	Main Dyke	19254 1

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Table A11.1

Traverse Number	Sample Number	Across- Dyke Position (metres)	Descript.	Mass Suscept.	Unit 1 or Unit 2
7	8401.24	78.50	Main Dyke	9098	1
7	8401.39	84.30	Main Dyke	8405	1
7	8401.54	88.25	Main Dyke	6169	1
7	8401.53	88.85	Main Dyke	5481	1
7	8401.55	89.75	Main Dyke	5592	1
7	8401.40	90.60	Main Dyke	5251	1
7	8401.46	104.70	Chill.Mar	31201	1
8		110.00	Half-Width		
8	8205.04	42.75	Main Dyke	4776	1
8	8205.06	103.90	Main Dyke	10686	1
8	8205.03	104.00	Main Dyke	7824	1
8	8205.01	106.85	Main Dyke	8300	1
8	8205.02	107.75	Main Dyke	6741	1
9		93.00	Half-Width		
9	8403.02	-99.00	Sat. Dyke	22596	1
9	8403.01	-99.00	Sat. Dyke	25875	1
10		93.28	Half-Width		
10	8404.23	-98.03	Hostrock	11095	Hostrock
10	8404.22	-97.13	Hostrock	28072	Hostrock
10	8404.21	-96.26	Hostrock	17639	Hostrock
10	8404.24	-95.18	Hostrock	11141	Hostrock
10	8404.20	-95.05	Hostrock	16648	Hostrock
10	8404.19	-94.76	Hostrock	19944	Hostrock
10	8404.18	-94.42	Hostrock	20311	Hostrock
10	8404.17	-93.99	Hostrock	12063	Hostrock
10	8404.16	-93.63	Hostrock	--	Hostrock
10	8404.15	-93.28	Hybrid?	6581	1
10	8202.05	-93.28	Volatile?	543	1
10	8202.02	-93.28	Volatile?	1717	1
10	8202.08	-93.28	Volatile?	9380	1
10	8404.14	-93.08	Chill.Mar	15754	1
10	8404.13	-92.63	Chill.Mar	15195	1
10	8404.12	-91.23	Main Dyke	9301	1
10	8404.11	-89.58	Main Dyke	9044	1
10	8202.10	-82.58	Main Dyke	7757	1
10	8404.10	-59.83	Main Dyke	10445	1
10	8202.11	-51.73	Main Dyke	5763	2
10	8404.08	-42.73	Main Dyke	13378	1
10	8404.07	-29.23	Main Dyke	3048	2
10	8404.06	-6.73	Main Dyke	6855	2
10	8404.09	4.28	Main Dyke	8240	2
10	8404.05	21.28	Main Dyke	6799	2
10	8404.04	31.28	Main Dyke	6850	2
10	8404.03	38.78	Main Dyke	7728	2
10	8404.02	46.28	Main Dyke	7425	2
10	8404.01	54.28	Main Dyke	8727	2

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Table A11.1

Traverse Number	Sample Number	Across- Dyke Position (metres)	Descript.	Mass Suscept.	Unit 1 or Unit 2
11		80.25	Half-Width		
11	8201.04	-15.65	Main Dyke	8344	2
11	8201.03	32.75	Main Dyke	5059	2
11	8201.02	53.35	Main Dyke	7611	1
11	8201.01	75.15	Main Dyke	6363	1
12		92.50	Half-Width		
12	8206.04	-85.90	Main Dyke	8822	1
12	8206.01	-81.90	Main Dyke	11115	1
12	8206.03	-60.50	Main Dyke	14085	1
12	8206.02	-55.35	Main Dyke	14038	1
13		92.50	Half-Width		
13	8420.01	-104.70	Sat. Dyke	16880	1
13	8420.05	-92.00	Main Dyke	11320	1
13	8420.02	-91.00	Main Dyke	10820	1
13	8420.03	-89.85	Main Dyke	9918	1
13	8420.04	-87.35	Main Dyke	9553	1
14		110.00	Half-Width		
14	8418.08	-153.30	Sat. Dyke	8497	1
14	8207.10	-153.00	Sat. Dyke	11341	1
14	8418.07	-152.00	Sat. Dyke	13111	1
14	8418.10	-152.00	Sat. Dyke	11932	1
14	8207.13	-151.80	Sat. Dyke	10848	1
14	8418.13	-109.50	Altered	26063	1
14	8207.09	-108.50	Altered	14505	1
14	8418.12	-107.25	Main Dyke	7810	1
14	8418.04	-95.75	Main Dyke	10185	1
14	8207.08	-93.50	Main Dyke	9671	1
14	8418.03	-78.65	Main Dyke	11343	1
14	8418.02	-63.00	Main Dyke	14458	1
14	8418.15	-52.50	Main Dyke	14389	1
14	8207.15	-35.50	Main Dyke	9302	2
14	8418.16	-21.50	Main Dyke	6173	2
14	8207.07	-3.50	Main Dyke	947	2
14	8418.01	1.50	Main Dyke	181	2
14	8418.17	6.00	Main Dyke	5424	2
14	8418.18	15.50	Main Dyke	8578	1
14	8418.11	25.00	Main Dyke	94	2
14	8418.19	44.50	Main Dyke	13744	2
14	8418.20	60.50	Main Dyke	11976	2
14	8418.21	74.50	Main Dyke	9869	1
14	8207.06	83.00	Main Dyke	10056	1
14	8418.22	91.85	Main Dyke	8027	1
14	8418.23	104.25	Main Dyke	7980	1
14	8418.24	107.05	Main Dyke	8434	1
14	8207.02	108.35	Main Dyke	8481	1
14	8207.04	108.85	Chill. Mar	10769	1
14	8207.01	110.00	Chill. Mar	11297	1
14	8207.03	110.00	Chill. Mar	10554	1
14	8207.05	110.00	Chill. Mar	12272	1

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Table A11.1 (continued)

Traverse Number	Sample Number	Across- Dyke Position (metres)	Descript.	Mass Suscept.	Unit 1 or Unit 2
15		74.00	Half-Width		
15	8208.09	-74.00	Chill. Mar	9637	1
15	8208.08	-60.00	Main Dyke	12775	1
15	8208.07	-50.35	Main Dyke	11550	1
15	8208.06	-30.65	Main Dyke	10488	1
15	8208.03	-19.00	Main Dyke	7641	1
15	8208.05	-15.35	Main Dyke	10695	1
15	8208.02	1.00	Main Dyke	9628	1
15	8208.04	13.00	Main Dyke	8519	1
16		42.50	Half-Width		
16	8209.01	-13.15	Main Dyke	12721	1
16	8209.02	1.00	Main Dyke	12478	1
16	8209.03	11.10	Main Dyke	10357	1
16	8209.04	17.35	Main Dyke	11729	1
16	8209.05	20.75	Main Dyke	12273	1
16	8209.06	32.10	Main Dyke	7512	1

APPENDIX 12: ESTIMATE OF ERRORS IN AEROMAGNETIC AND GROUND MAGNETIC MODELLING

A12.1 ESTIMATE OF ERROR RESULTING FROM CHOICE OF MAGNETIZATION DIRECTION

A12.1.1 Introduction

Modelling of dyke dip in Section 11.8 made two assumptions: (1) that the magnetization direction was aligned in the direction of the present Earth's field, (D/I) $350^{\circ} / 76^{\circ}$, and (2) that the dyke strike (for the type curves only) equaled $N70^{\circ}E$. The error caused by making these two assumptions can be assessed in a similar way, which is developed below.

A12.1.2 Theory

For purposes of modelling, dykes can be considered 2-D bodies of essentially infinite extent in the third (horizontal) dimension. As a consequence, the component of the Earth's field along the dyke makes no contribution to the magnetic anomaly produced above the dyke. Only the inclination of magnetization in the plane perpendicular to the dyke trend influences the shape of the anomaly over the dyke.

Both possible sources of error (1) and (2) can be tested by considering the effect of changing dyke strike on the inclination of the applied field in the plane perpendicular to the dyke. Let the Earth's field have declination 0° and an inclination angle, α . Let the angle between magnetic north and the dyke trend be given as β . Then the inclination in the plane perpendicular to the dyke trend (γ) is calculated from

$$\tan(90 - \gamma) = \tan(90 - \alpha) \cdot \sin(\beta) \quad (A12.1)$$

A12.1.3 Calculation of Errors

The two sources of error are evaluated as follows:

(1) The true magnetization direction of the dyke will lie along a great circle between that of the present Earth's field (PEF) and that of the remanent direction (Fig. 10.6). The declination difference between the PEF (350°) and the average remanent direction ranges from 0 to 50° (Fig. 10.6). For a value of $\alpha = 76^{\circ}$ (the PEF value) and β equal to 40° (90° minus 50°), γ only steepens by 5° . The most extreme case assumes a Q value much less than 1 and a remanence direction of $D/I = -265^{\circ}/60^{\circ}$. β approaches zero and γ approaches 90° (i.e. vertical) in which case, the inclination error is 14° ($90^{\circ} - 76^{\circ}$).

(2) The declination difference between dyke trend and the value of 70° used in generating the type curves effects the inclination of the magnetization direction. In equation A12.1 let β equal 90° minus the declination difference. Differences in dyke trend even up to 50° will have only a minimal impact on the inclination of the applied field in the plane perpendicular to the dyke.

A12.2 ERROR RESULTING FROM DEPTH EXTENT USED IN MODELLING

Aeromagnetic and ground magnetic profiles were modelled in two ways, both interactively and using type curves. Both approaches used the computer program MAGRAV2 (Broome, 1986) and in all cases the depth extent of the modelled dyke was assumed to be 5 km. In reality this estimate is probably too low. However, the results in Table A12.1 show that the effect of doubling the depth extent to 10 km has an insignificant effect on the anomaly. The maximum error after the average difference is subtracted is 5 nT for the 400 m wide model-dyke and 1 nT for the 100 m wide model-dyke.

Table A12.1: Effect of changing the depth extent of the modelled dyke. In each case the given value equals the difference between the anomaly calculated for the two depth extents (5 and 10 km). Units are nT, magnetization is 1.5 A/m and 'flight elevation' is 0.12 km. Calculated using MAGRAV2 (Broome, 1986)

position along traverse (km)	400 m wide dyke			100 m wide dyke		
	dip= 90°	dip= 70°S	dip= 70°N	dip= 90°	dip= 70°S	dip= 70°N
0.00	10.52	9.41	6.40	2.64	2.37	1.61
0.10	10.63	9.21	6.60	2.67	2.31	1.66
0.20	10.72	9.00	6.79	2.70	2.26	1.70
0.30	10.81	8.78	6.97	2.72	2.21	1.75
0.40	10.88	8.54	7.17	2.74	2.15	1.80
0.50	10.95	8.30	7.36	2.75	2.09	1.85
0.60	11.00	8.05	7.55	2.76	2.03	1.89
0.70	11.04	7.79	7.75	2.78	1.96	1.94
0.80	11.06	7.53	7.95	2.79	1.89	1.99
0.90	11.08	7.26	8.14	2.79	1.83	2.04
1.00	11.08	6.98	8.33	2.79	1.76	2.09
1.10	11.06	6.70	8.52	2.79	1.69	2.13
1.20	11.03	6.40	8.71	2.78	1.60	2.19
1.30	10.98	6.12	8.89	2.76	1.54	2.23
1.40	10.92	5.83	9.08	2.75	1.46	2.28
1.50	10.84	5.54	9.25	2.73	1.39	2.33
1.60	10.75	5.25	9.43	2.71	1.32	2.37
1.70	10.64	4.96	9.60	2.68	1.24	2.41
1.80	10.52	4.66	9.76	2.65	1.17	2.46
1.90	10.38	4.38	9.92	2.61	1.09	2.49
2.00	10.23	4.09	10.07	2.58	1.02	2.53
2.10	10.08	3.81	10.21	2.54	0.95	2.56
2.20	9.90	3.53	10.34	2.49	0.88	2.60
2.30	9.71	3.25	10.47	2.44	0.81	2.64
2.40	9.50	2.99	10.58	2.39	0.75	2.66
2.50	9.29	2.72	10.68	2.33	0.68	2.69
2.60	9.06	2.46	10.78	2.28	0.61	2.71
2.70	8.83	2.22	10.86	2.23	0.55	2.73
2.80	8.59	1.97	10.92	2.16	0.49	2.75
2.90	8.33	1.73	10.98	2.09	0.43	2.76
3.00	8.08	1.50	11.02	2.03	0.37	2.77
3.10	7.81	1.27	11.05	1.97	0.31	2.78
3.20	7.55	1.05	11.07	1.90	0.26	2.78
3.30	7.26	0.84	11.07	1.82	0.21	2.78
3.40	6.99	0.64	11.05	1.76	0.16	2.79
3.50	6.70	0.44	11.02	1.68	0.11	2.78
3.60	6.42	0.25	10.98	1.61	0.05	2.77
3.70	6.13	0.07	10.92	1.53	0.01	2.75
3.80	5.84	-0.11	10.85	1.46	-0.04	2.73
3.90	5.56	-0.28	10.75	1.39	-0.07	2.71
4.00	5.26	-0.44	10.66	1.32	-0.11	2.69

The maximum deviation from the average for each model is 5 nT for 400m and 1 nT for 100 m wide dykes.

**APPENDIX 13: TYPE CURVES FOR MODELLING AEROMAGNETIC AND
GROUND MAGNETIC DATA**

Fig. A13.1: Type curves generated using the computer program MAGRAV2 (Broome, 1986). Dip and magnetization contrast (M) parameters listed on each diagram. For all diagrams, the assumed flight elevation was 120 m and the depth extent of the dyke was assumed to be 5 km.

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Fig. A13.1

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Fig. A13.1

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Fig. A13.1

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Fig. A13.1

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Fig. A13.1

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Fig. A13.1

Fig. A13.1

GREAT ABITIBI DYKE

END

1|6.0|2.90

FIN